Special Report

# Precast Prestressed Concrete Horizontally Curved Bridge Beams

prepared by

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This report discusses the concept, analysis and design procedures, design alternatives and fabrication techniques recommended for precast prestressed horizontally curved bridge beams. Comparisons of curved precast bridge superstructures with steel and cast-in-place concrete demonstrate the aesthetic and economic advantages a precast concrete solution offers to bridge owners and engineers. Three separate appendixes contain plans and details, design charts and a design example applying the design aids.

# CONTENTS

# 1. INTRODUCTION

New interchanges off limited access highways often require horizontally curved medium length bridge beams. These bridge beams have been made almost exclusively of steel where falsework restrictions preclude cast-in-place concrete construction. This report presents results of a project sponsored by the Prestressed Concrete Institute (PCI) to develop standards for precast prestressed horizontally curved bridge beams.

The idea to develop horizontally curved bridge beams won PCI's Industry Advancement Award in 1985. This award winning idea was developed from a precast prestressed curved beam project constructed in Pennsylvania. PCI subsequently issued a request for proposals to develop this idea. ABAM Engineers of Federal Way, Washington, was selected to pursue this effort.

This report summarizes the concept, analysis and design procedures, and fabrication techniques recommended for precast prestressed horizontally curved bridge beams. Comparisons of curved precast bridge superstructures with steel and cast-in-place concrete demonstrate the aesthetic and economic advantages a precast concrete solution offers to bridge owners and engineers.

# 2. CONCEPT DESCRIPTION

A concept for horizontally curved precast prestressed concrete beams is presented. The concept uses the basic idea that won PCI's Industry Advancement Award for 1985. Several alternatives to this basic idea for materials, fabrication and erection procedures, beam geometry, and beam cross sections were evaluated. Descriptions of these alternatives are listed in Table 1. Concept 8, a trapezoidal box beam, was selected for development in this report. Design charts and conceptual drawings are presented for 5 and 6 ft (1.52 and 1.83 m) deep precast box beams. These charts are intended to present preliminary prestressing strand and concrete strength criteria for various spans and beam spacings. Appendix A contains conceptual design plans and details.

The concept uses long precast concrete beams spanning between supports. Chorded sections [20 ft (6.10 m) long] are used to approximate curved geometry (Figs. 1 and 2). Diaphragms are provided at angle points between these chorded sections. This chord length produces a 2 in. (51 mm) offset on a 300 ft (91.5 m) radius curve. The beams are chorded in plan and in profile. Individual precast beams are post-tensioned together in the field to form continuous structures.

Trapezoidal box beams are used to produce a torsionally rigid section that is aesthetically pleasing (Fig. 3). Span to depth ratios for bridge superstructures constructed with 5 ft (1.52 m) deep precast box beam elements can be 27 to 1 for interior spans and 23 to 1 for exterior spans. These span to depth ratios are comparable to bridges constructed from composite welded steel girders and from cast-in-place post-tensioned box girders.

Post-tensioning tendons are placed inside the beam void and are deflected horizontally and vertically at diaphragms between chorded sections. The tendons, therefore, form a string polygon that approximates a parabolic shape in profile and the curve radius in plan (Fig. 4). Tendons are bonded to the cross section at each diaphragm but are not continuously bonded along the tendon length.

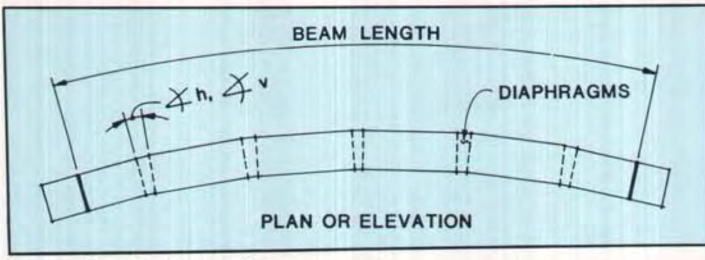


Fig. 1. Chorded geometry.

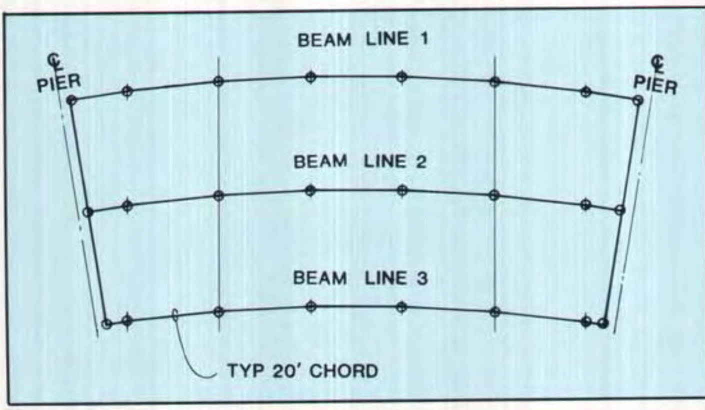


Fig. 2. Schematic layout.

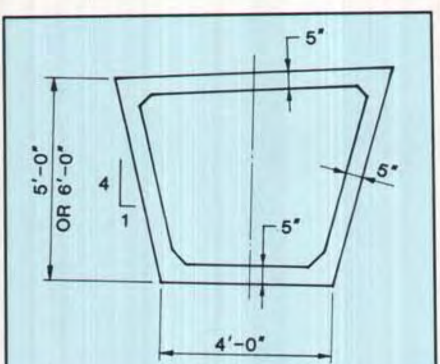


Fig. 3. Typical section.

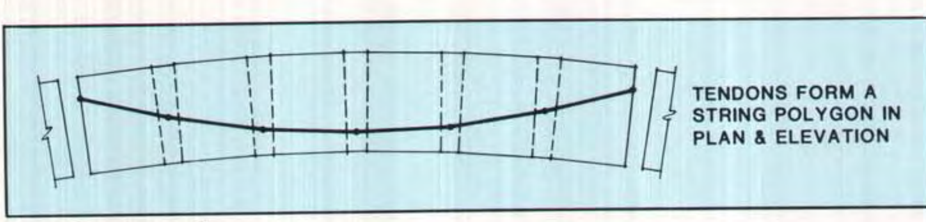


Fig. 4. Tendon profile.

Table 1. Precast prestressed concrete horizontally curved bridge beam concepts.

| Concept | Design variable | | | Manufacturing variable | | |
|---|---|---|---|---|---|---|
| | Cross section | Concrete density* (pcf) | Continuity at center pier | Casting method† | Void form‡ | Number of beams per project |
| 1 | Rectangular box | 160 | Yes | Full length | Expendable polystyrene | 24 |
| 2 | Rectangular box | 160 | Yes | Full length | Steel and wood | 24 |
| 3 | Rectangular box | 160 | Yes | Segmental | Steel and wood | 24 |
| 4 | Rectangular box | 160 | No | Full length | Steel and wood | 24 |
| 5 | Rectangular box | 160 | Yes | Full length | Steel and wood | 6 |
| 6 | Rectangular box | 160 | Yes | Segmental | Steel and wood | 6 |
| 7 | Rectangular box | 125 | Yes | Full length | Steel and wood | 24 |
| 8 | Trapezoidal box | 160 | Yes | Full length | Steel and wood | 24 |

* Density includes reinforcement.

† Full length casting: Chorded sections and diaphragms are cast monolithically.
Segmental casting: Chorded segments are cast separately then moved to an assembly area for integration into full length beams.

‡ Expendable polystyrene void: Solid sacrificial expendable polystyrene forms entire void.
Steel and wood forms: Reusable steel forms for the sides of the interior; sacrificial wood forms for the soffit of the top flange. This is a two-stage casting.

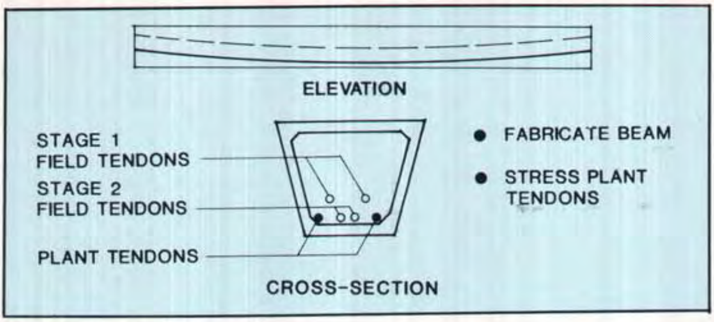


Fig. 5. Step 1.

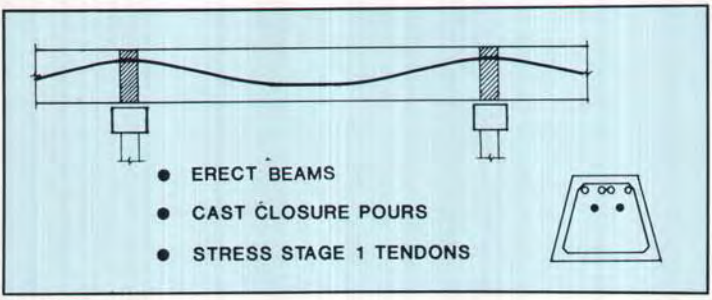


Fig. 6. Step 2.

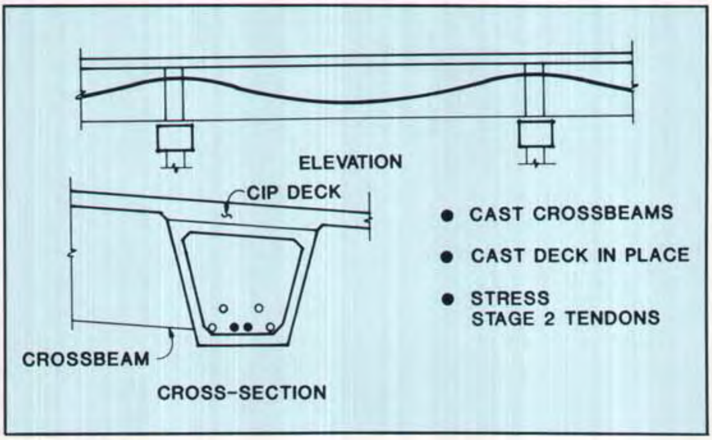


Fig. 7. Step 3.

The concept allows individual beam lines to be bent horizontally to specific design radii and to provide different profiles for individual beam lines to build in vertical curves and varying superelevations. A table of precast beam geometry would be developed for each project.

Construction of a bridge made from precast prestressed horizontally curved beams involves three basic steps, illustrated in Figs. 5, 6 and 7.

■ Step 1 (Fig. 5): Beams are fabricated full length in the plant in specially designed formwork. Beams are cast in two stages. Stage 1 includes the soffit and webs of the chorded sections, end diaphragms, and diaphragms between chorded segments. Ducts are provided by plant post-tensioning tendons and for Stage 1 and Stage 2 field post-tensioning tendons. The beam deck is cast in Stage 2. Beam casting is complete prior to removing the beam from the form. Beams are lifted out of the form and transported to a yard storage/stressing area as reinforced concrete members. Plant post-tensioning tendons are stressed.

■ Step 2 (Fig. 6): Beams are transported to the site and erected. Ducts for Stage 1 and Stage 2 field post-tensioning tendons are spliced over interior supports. Closure pours are made between beams over interior supports. Stage 1 tendons are stressed, creating continuous beams.

■ Step 3 (Fig. 7): Cross beams are cast at the midpoint or at the third points along the span at the nearest diaphragm locations. The bridge deck is cast. Stage 2 tendons are stressed, placing the deck into compression. Traffic barriers, overlays, and expansion joints are placed, completing the bridge construction.

This horizontally curved prestressed precast beam concept was selected over the other concepts (see Table 1) because it generally:

- Improved quality
- Reduced costs
- Improved aesthetics

Quality was enhanced using a two-stage casting with removable inner forms for Stage 1. Inner surfaces and thicknesses of the beam soffit and webs can be inspected and positioning of post-tensioning tendons can be carefully established and verified.

Labor costs to produce full length beams are reduced by minimizing fabrication steps. Also, sloping sides delete the requirement to move back beam side forms to lift beams from the form. Material costs are reduced by eliminating costly inner void forms.

Aesthetics are improved by utilizing sloping beam sides in lieu of vertical sides.

Alternative design and fabrication variations of this concept may be appropriate for specific project conditions. These variations are discussed later in this report.

## 3. COST COMPARISONS

Cost estimates were developed for bridge superstructures of precast concrete, cast-in-place concrete, and structural steel. The precast alternative includes the cost of cast-in-place concrete cross beams, bridge deck, and traffic barriers. The steel alternative includes the cost of a concrete bridge deck and traffic barriers.

A 24-beam project was assumed for this cost comparison. Projects requiring fewer beams will be more costly per square foot for the precast alternative.

The unit superstructure cost range (per square foot) for the precast concept versus the cast-in-place concrete design and the steel girder bridge design is shown in Fig. 8. This figure shows that the precast beam concept is cost competitive with the steel beam design when the unit steel price, in place and painted, is more than \$1 per pound (\$2000 per ton). Typical unit prices on curved steel girders range from \$1.00 to \$1.50 per pound.

Precast beams are competitive with cast-in-place concrete box girders when the in-place unit concrete price exceeds \$530 per cubic yard. Typical cast-in-place concrete bridges will cost between \$400 and \$700 per cubic yard (complete with reinforcing bars and

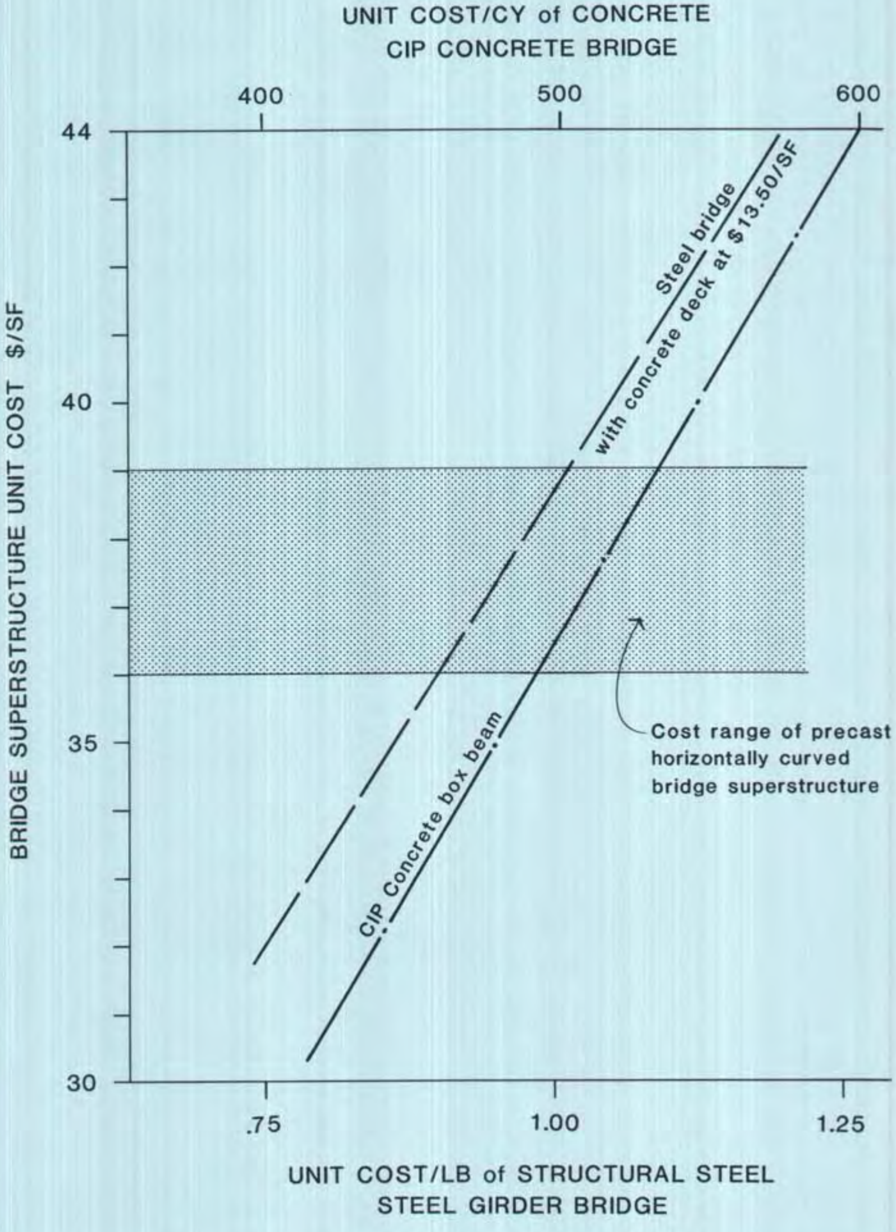


Fig. 8. Comparison of unit superstructure costs. Precast concrete beam bridge versus steel girder bridges and cast-in-place concrete bridges.

post-tensioning). Difficult shoring conditions will add to this cost. Also, certain projects will not allow shoring and will therefore exclude cast-in-place concrete designs.

Horizontally curved bridges made from precast concrete beams are competitive with steel girder bridges and cast-in-place concrete bridges. The amount of competitive edge will vary with local project and market conditions.

# 4. ANALYSIS AND DESIGN

Design of the curved precast beams addresses flexure, shear, torsion, distortion, and tendon anchoring and deflection forces. A computer model was developed for a 120 ft (36.6 m) span 5 ft (1.52 m) deep girder on a 300 ft (91.5 m) radius to better understand beam behavior. The beams, cross beams, and deck were modeled using a grillage of one-dimensional elements. From this model, analysis techniques were developed for preliminary design.

Flexure and shear forces can be computed as if the beam were tangent, giving consideration to the extra length of the outside beam line that results from horizontal curvature (Fig. 9). Critical stress conditions are identified for each step of the construction process.

The beam is post-tensioned at the

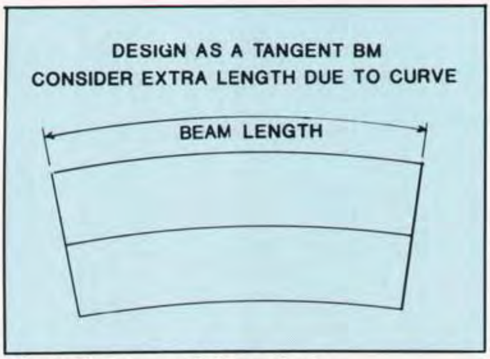


Fig. 9. Flexure and shear design.

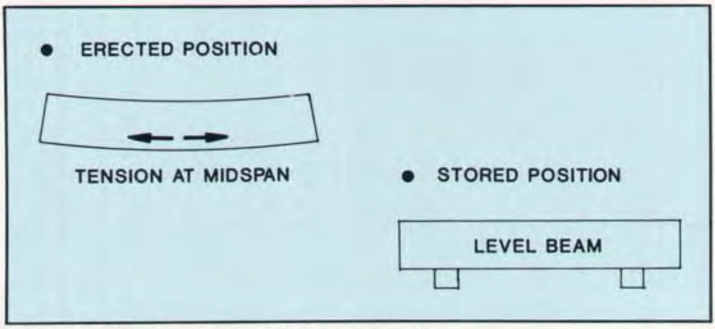


Fig. 10. Critical stress condition (at plant).

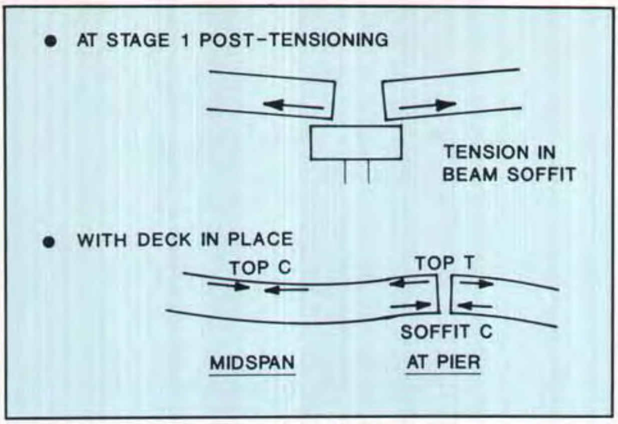


Fig. 11. Critical stress condition (Stage 1).

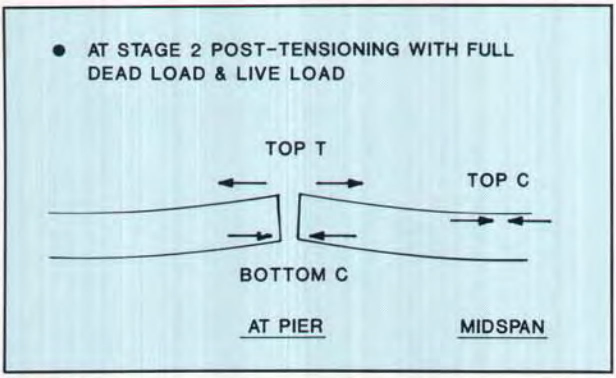


Fig. 12. Critical stress condition (Stage 2).

plant to carry its own weight (Fig. 10). In this condition, long beams generally experience downward deflection. Due to the beam curvature, the bunking, transportation, and lifting locations are positioned inward from the ends of the beam over an appropriate diaphragm to provide overturning stability. The beam prestressing is also adjusted to minimize camber growth in the stored position. The beam profile in the form is adjusted for the vertical geometry and for expected elastic and creep deflections.

The critical stress condition due to stressing Stage 1 tendons is tension in the beam soffit over interior supports (Fig. 11). Temporary tension at this location is resisted by a positive moment connection between beams. Upon placing the cross beams and deck, the critical stress condition becomes compression in the soffit over the piers. Tension stresses in the top of the beams over the piers and compressive stresses in the top of the beams near midspan can also control the design.

The critical stress conditions at Stage 2, with the full superimposed dead load and live load in place, are tension in the bridge deck and compression in the beam soffit over interior supports and compression in the top of the beam near midspan (Fig. 12). The compressive stress at midspan is theoretically large in

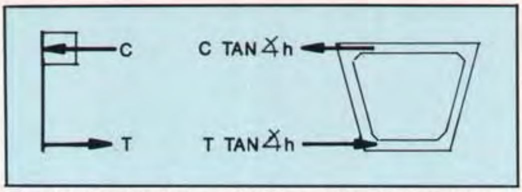

Fig. 13. Radial forces due to turning flexural forces.

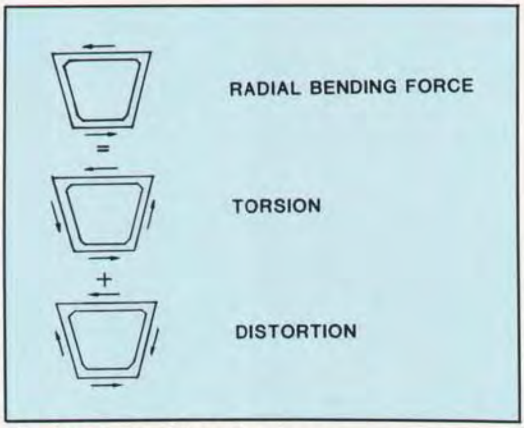

Fig. 14. Torsion/distortion forces.

the girder top flange and small in the adjacent cast-in-place deck. Creep effects, however, will redistribute the large compressive stress from the beam into the deck. Because the creep effect is not considered in the preliminary calculations, the beams designed in this report use a maximum compressive stress of $0.5 f_c'$ in the top flange of the precast beam at midspan. Compression in the beam soffit near interior supports generally determines the required concrete compressive stress, based on an allowable compressive stress of $0.4 f_c'$.

An ultimate strength check is required. It is recommended that the computation be done using the capacity of unbonded post-tensioned tendons. Additional mild steel can be added to achieve the required flexural strength. Mild steel reinforcement is used across all cold joints along the beam length. This controls cracking and improves ductility, which is especially attractive in seismic risk areas.

Other considerations need to be accounted for in horizontally curved precast prestressed concrete bridge beams. At each horizontal angle point, between chorded sections, the internal flexural forces resisting the vertical bending moment turns through a horizontal angle (Fig. 13). Angular deflection of these forces places horizontal forces in the top and bottom surfaces of the beams. These in-plane forces can be broken into torsional and distortion components (Fig. 14). The torsional component is reacted by the box section and the distortion component is resisted by the diaphragm between chorded segments.

Significant beam torsions are produced only by the beam self weight

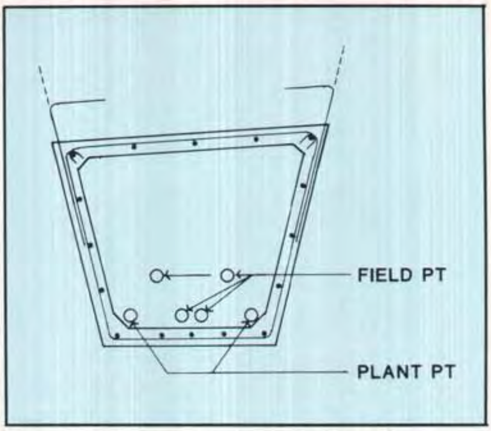

Fig. 15. Reinforcement at typical section.

acting on a simple span and by the bridge deck dead load acting on a continuous beam. Subsequent twisting of the curved beams is resisted by the bridge deck and cross beams.

Shear and torsion design is performed by distributing the torsional resistance into individual web shears and adding web shears reacting vertical forces. Thickening of webs may be required for longer beams.

Tendon deflection and anchoring forces are reacted by the end blocks and the diaphragms between chorded segments.

Beam span charts have been developed that show the required number of post-tensioning strands per beam for various spans and beam spacings. Required concrete strengths for the design are also shown. High concrete strengths can be used to increase girder spacing. Bridge horizontal curvature has little influence on post-tensioning requirements. Therefore, designers can use design charts for any bridge having the same outside beam length. Design charts use HS-20 live load. Beam charts are included in Appendix B and a design example using the charts is included in Appendix C.

Typical reinforcement and post-tensioning (PT) placement are shown in Fig. 15.

# 5. DESIGN ALTERNATIVES

Situations are presented that require a concept to offer flexibility to suit the particular requirements of an owner, bridge engineer, or precaster. Several variations in design can be employed to enhance the usefulness of horizontally curved precast concrete beams.

## Cross Section

A rectangular box section can be used in lieu of a trapezoidal box section. Design curves for trapezoidal box cross sections may be used if rectangular cross sections have properties similar to trapezoidal cross sections shown.

## Thickening of Soffit Slab at Interior Piers

The soffit of the beam near the support can be thickened to reduce compressive stresses and therefore the required concrete compressive stress. Design Chart 11 can be compared to Design Chart 2 (Appendix B) to determine the amount of this reduction. Similarly, the thickness of the top flange of the precast beam could be increased in the midspan region to reduce compressive stresses near midspan.

### Elimination of the Second Stage of Field Post-Tensioning

The second stage of field post-tensioning can be eliminated. Additional mild steel is placed in the deck over the piers to control cracking and provide ultimate moment strength. This alternative is especially attractive for areas where the requirement to totally remove the concrete deck for future replacement exists. Comparison of Design Charts 12 and 2 shows the effect this alternative has on the number of prestressing strands and on the required concrete compressive strength.

### Use of Lightweight Concrete

Lightweight or semi-lightweight concrete can be used to reduce beam transportation and erection weight. Reductions in beam weight can be seen in Charts 7 and 10 (Appendix B).

## 6. FABRICATION TECHNIQUES

### Form Concept

A forming concept for fabricating full span length chorded beams was developed. The segments move and rotate along guide beams to provide the horizontal curvature (Fig. 16). The elevations of the guide beams can be adjusted using jacks to provide the vertical profile (Fig. 17). The segments are not twisted or warped. These variations can be accommodated in the cast-in-place deck.

### Beam Weight

The weight of precast concrete beams is a major concern. A maximum shipping weight of 314,000 lb (142,430 kg) (hauling equipment plus beam) was selected to identify limiting span lengths. This weight is equal to the P13 permit design load used on California's highway system.

Shipping these large loads requires special transporters (Fig. 18). There are units that have been used to transport girders of similar size. For instance, 13-axle transporters are available on the west coast. The 318,000 lb (144,245 kg) shipping weight places an axle load of 24 kips (107 kN) on axles 4½ ft (1.37 m) apart.

This is similar to the axle loads for the AASHTO military loading. The maximum shipping weight translates into an effective beam transportation weight of 254,000 lb (115,214 kg). This beam weight limits the shipping length of the 6 ft (1.83 m) deep section to 130 ft (39.6 m) and the 5 ft (1.52 m) deep section to 150 ft (45.7 m).

### Alternative Production Methods

Alternative production techniques also were investigated.

Individual 20 ft (6.10 m) long chorded beam segments could be fabricated and then assembled into span length beams at the plant. This option reduces beam forming costs but increases the number of production steps. This alternative may be advantageous on projects requiring a small number of beams.

Optional void materials could be used. The concept was designed around a two-pour beam casting using steel

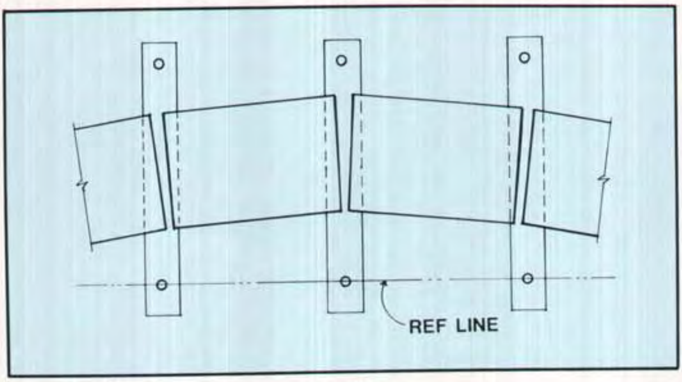


Fig. 16. Plan view of forming concept.

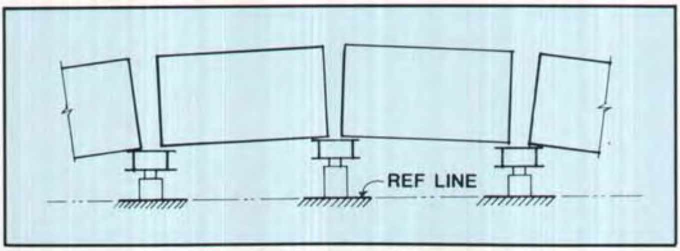


Fig. 17. Elevation of forming concept.

Fig. 18. Beam transporter.

inner forms with an expendable wood deck soffit form. Polystyrene or wood forms could be used. However, production problems with these expendable voids need to be carefully considered.

Beams can also be spliced in the field to reduce shipping weight and to produce longer spans.

## 7. CONCLUSION

A concept has been developed for precast prestressed concrete horizontally curved bridge beams. The concept uses trapezoidal box beams made of chorded segments to approximate curved plan and profile geometries. Tendons are placed inside the void of the beams. High strength concrete can be used to increase the beam spacing. Shipping restrictions limit practical beam span lengths, especially for 6 ft (1.83 m) deep units. Lightweight concrete or spliced beams can be used to overcome this limitation. Precast prestressed bridge beams can be a viable option for horizontally curved bridges, giving bridge owners and engineers an alternative to steel girders and to cast-in-place concrete structures.

## REFERENCE


1. Barnoff, Robert, M.; Nagle, Gordon; Suarez, Mario, G.; Geschwindner, Louis, F., Jr.; Merz, H. William, Jr.; and West, Harry, H.; "Design, Fabrication, and Erection of a Curved Prestressed Concrete Bridge With Continuous Girders," Transportation Research Record 950, 1985, pp. 136-140.


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**NOTE:** Discussion of this report is invited. Please submit your comments to PCI Headquarters by May 1, 1989.

# APPENDIX

- APPENDIX A — CONCEPTUAL DRAWINGS AND DETAILS
- APPENDIX B — DESIGN CHARTS
- APPENDIX C — DESIGN EXAMPLE

## APPENDIX A — CONCEPTUAL DRAWINGS AND DETAILS

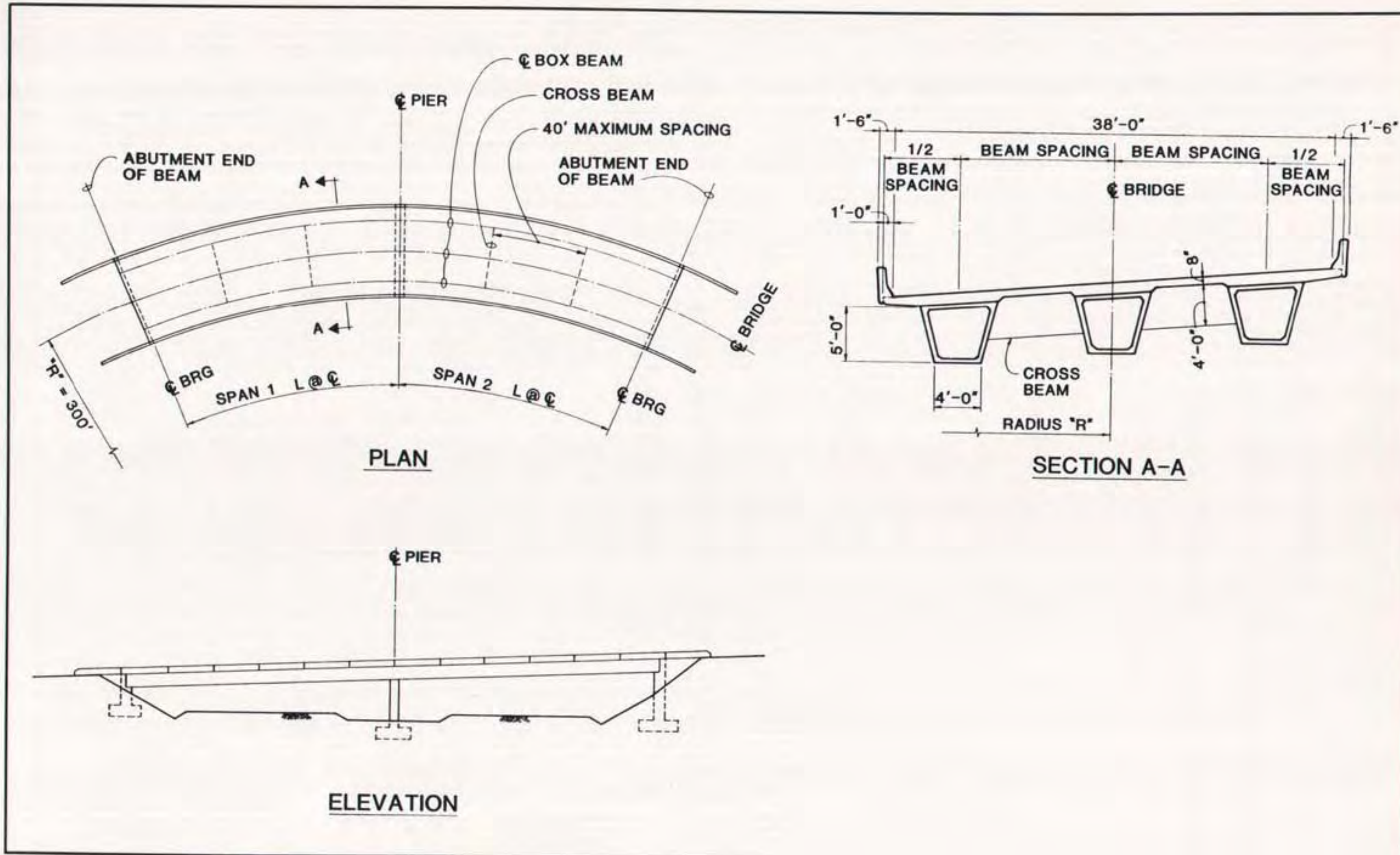



Fig. A1. Precast prestressed concrete horizontally curved bridge beams (typical bridge layout).

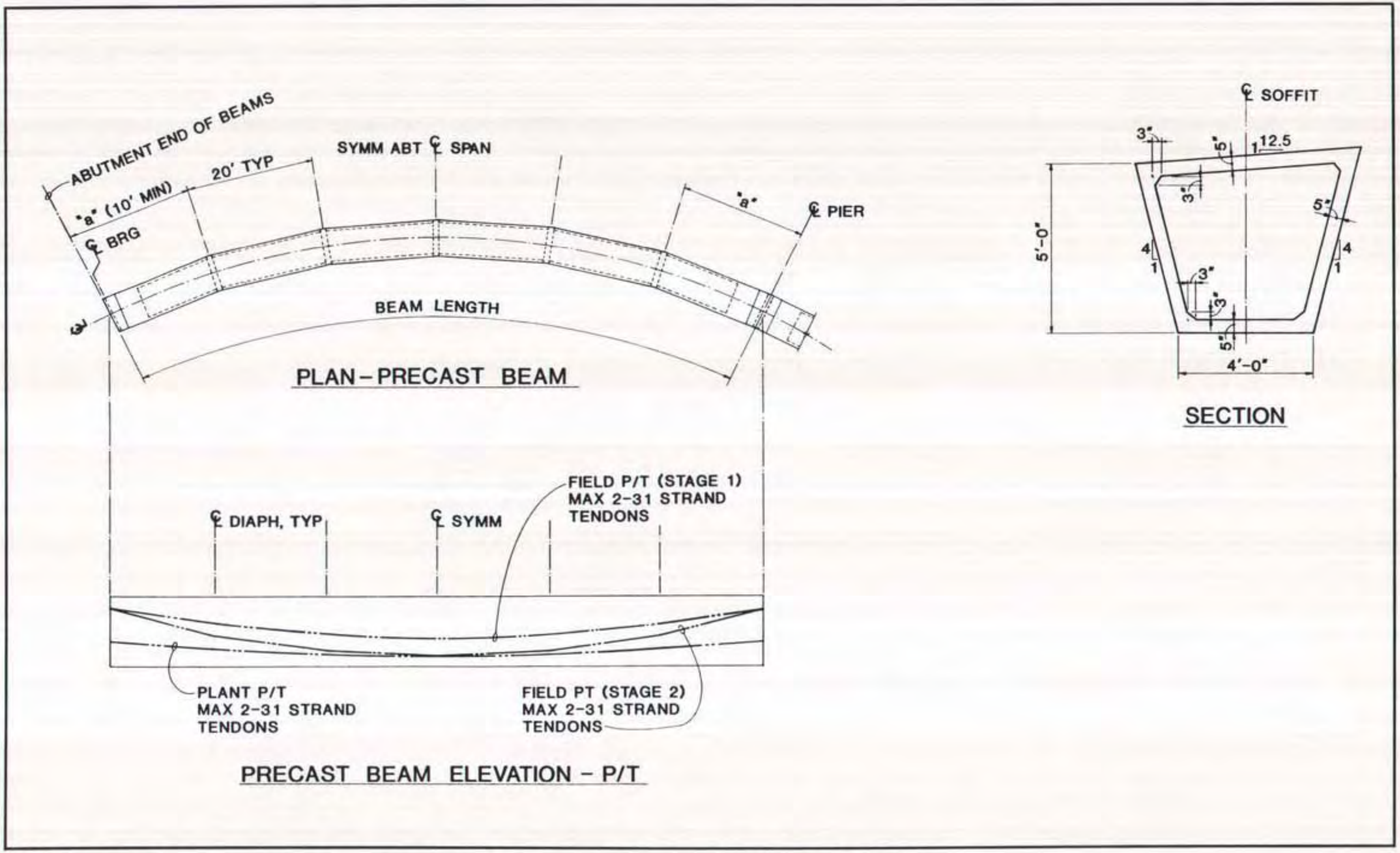



Fig. A2. Precast prestressed concrete horizontally curved bridge beams [5 ft (1.52 m) beam].

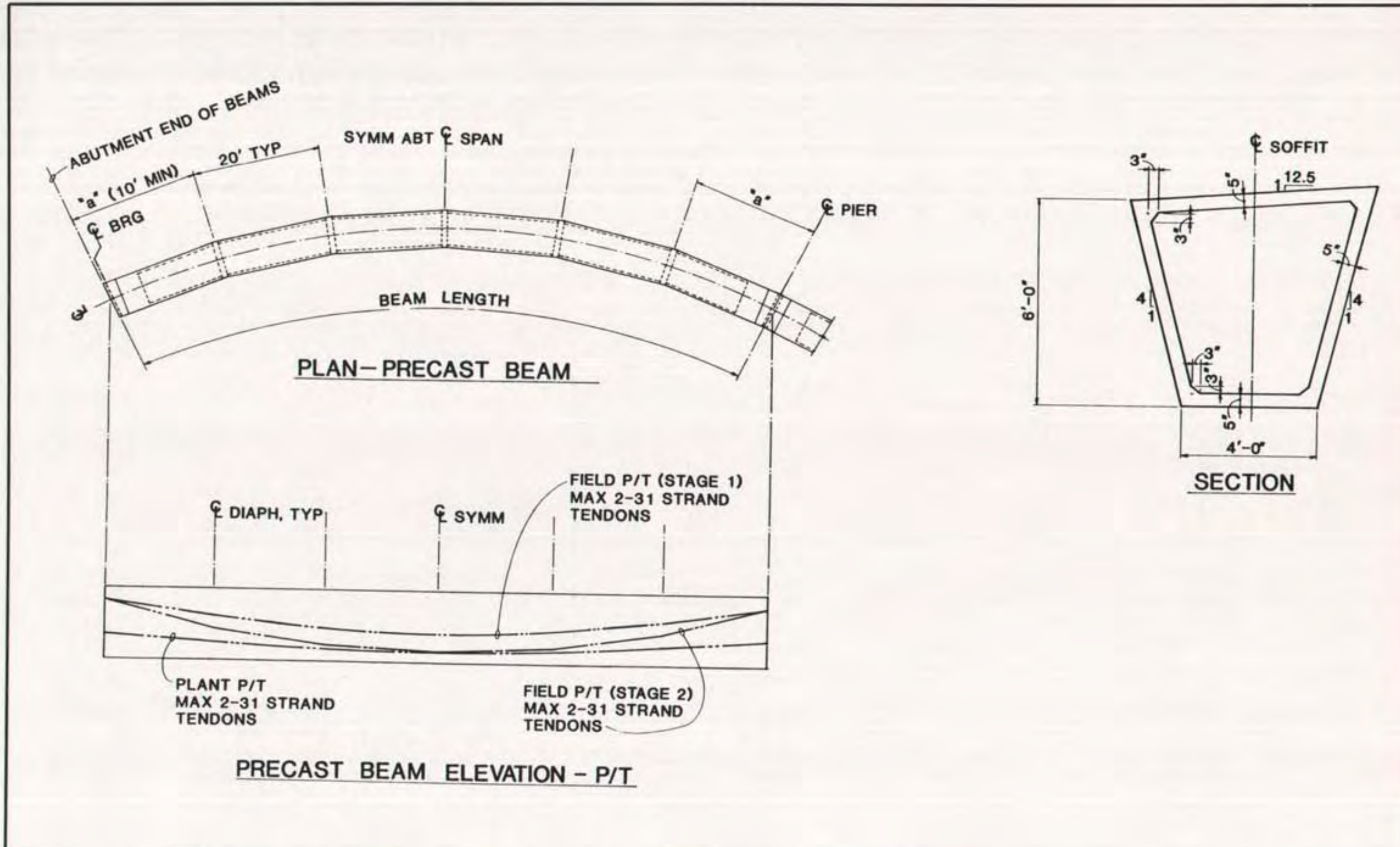



Fig. A3. Precast prestressed concrete horizontally curved bridge beams [6 ft (1.83 m) beam].

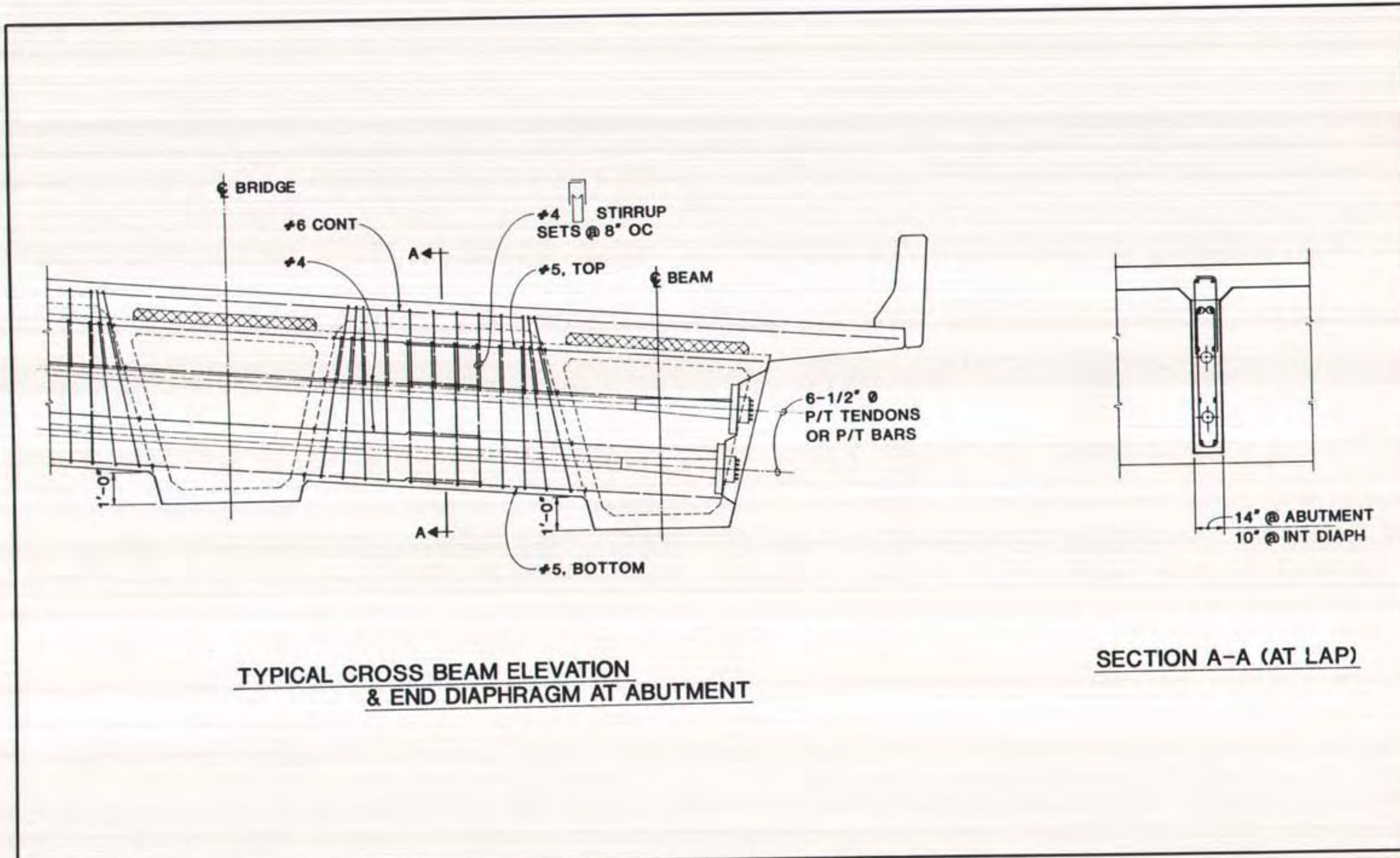



Fig. A4. Precast prestressed concrete horizontally curved bridge beams (cross beam details).

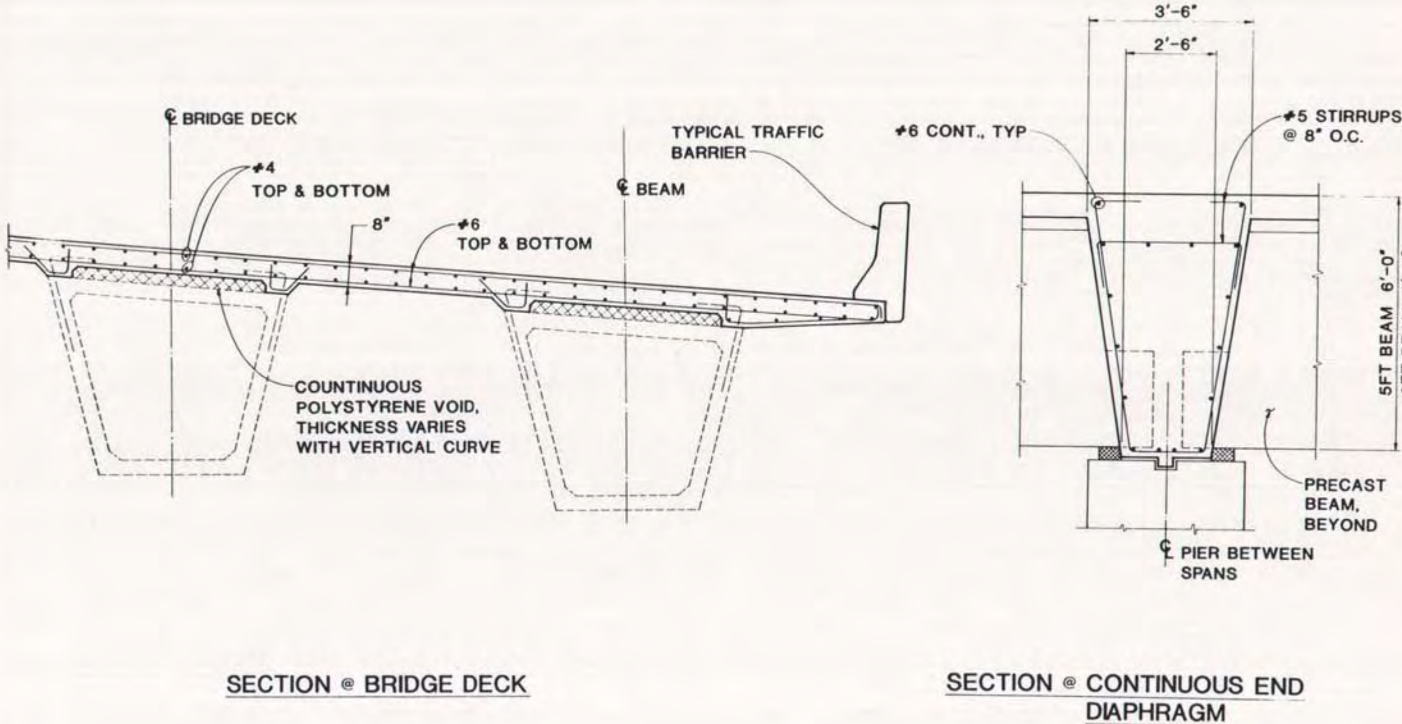



Fig. A5. Precast prestressed concrete horizontally curved bridge beams (deck and pier diaphragm details).

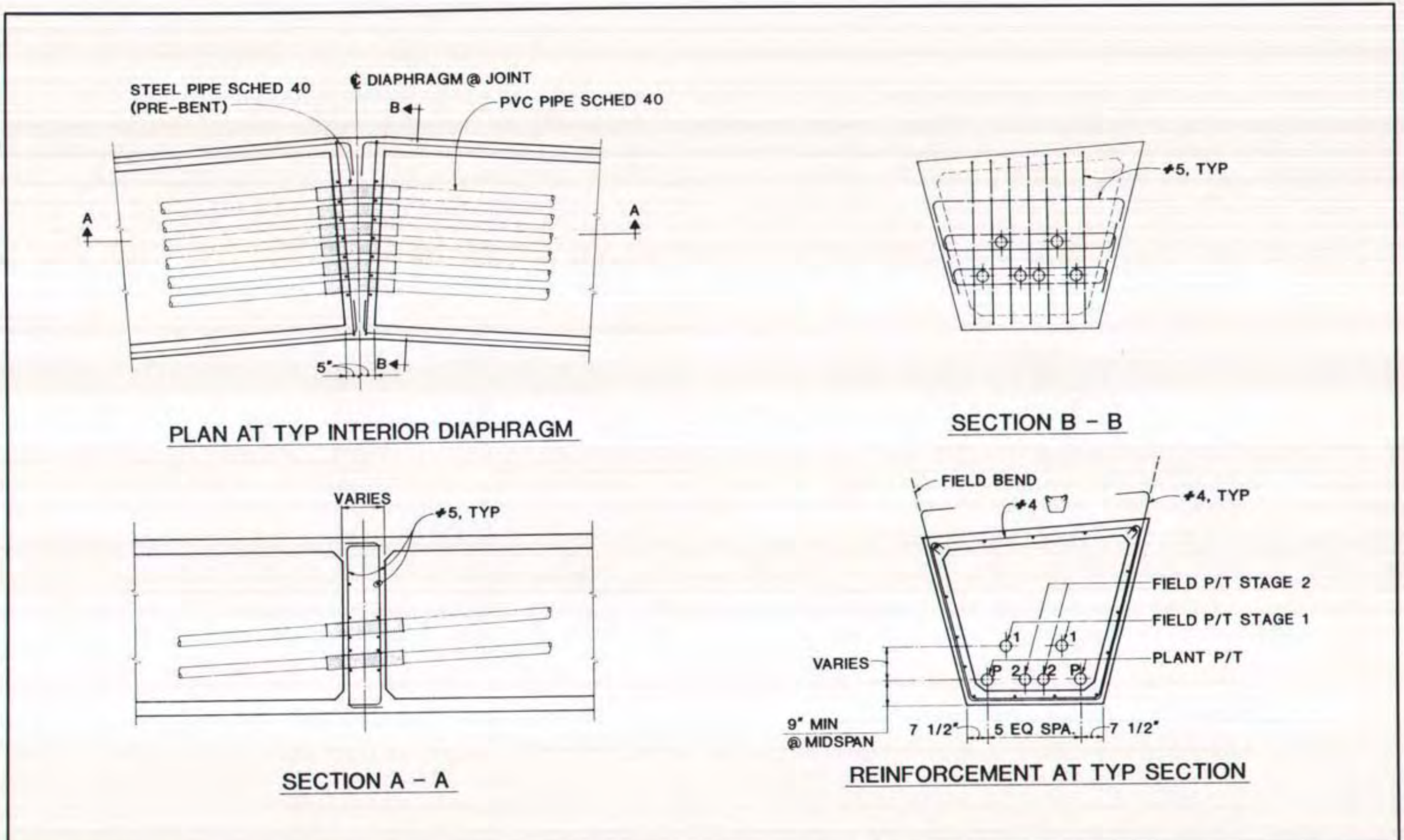



Fig. A6. Precast prestressed concrete horizontally curved bridge beams (typical cross section and tendon deflection details).

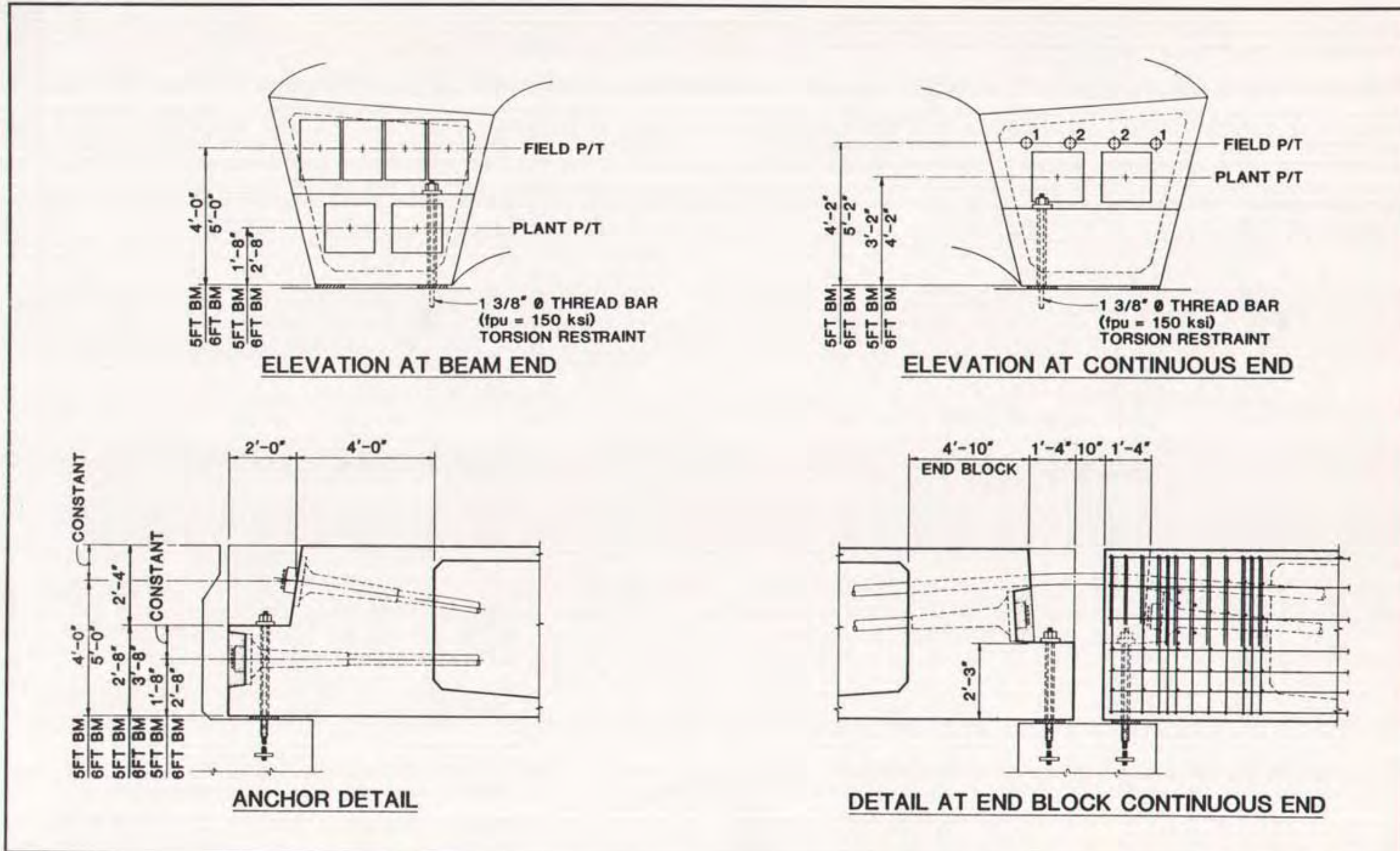



Fig. A7. Precast prestressed concrete horizontally curved bridge beams (sections and details).

# APPENDIX B — DESIGN CHARTS

## GENERAL

Fig. B. Key plan, sections, and notes to be used with charts.

## 5 FT (1.52 M) DEEP BOX BEAM

Chart 1. Total post-tensioned strand requirement (interior span beam).

Chart 2. Total post-tensioned strand requirement (exterior span beam).

Chart 3. Post-tensioned strand requirement (interior span beam, beam spacing = 13 ft).

Chart 4. Post-tensioned strand requirement (exterior span beam, beam spacing = 8 ft).

Chart 5. Post-tensioned strand requirement (exterior span beam, beam spacing = 10 ft).

Chart 6. Post-tensioned strand requirement (exterior span beam, beam spacing = 13 ft).

Chart 7. Beam shipping weight.

## 6 FT (1.83 M) DEEP BOX BEAM

Chart 8. Total post-tensioned strand requirement (interior span beam).

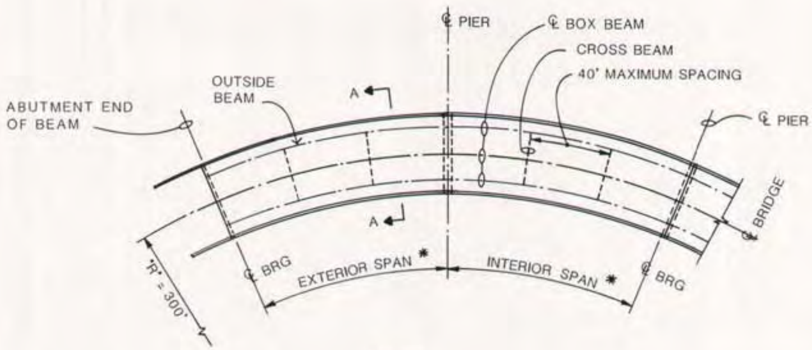
Chart 9. Total post-tensioned strand requirement (exterior span beam).

Chart 10. Beam shipping weight.

## DESIGN ALTERNATIVES, 5 FT (1.52 M) DEEP BOX BEAM

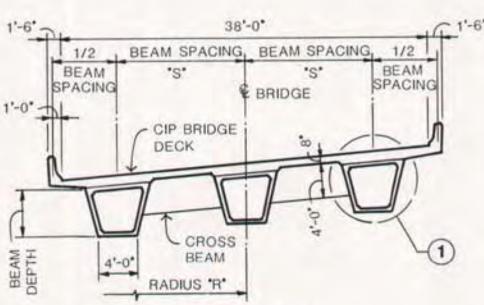
Chart 11. Total post-tensioned strand requirement (exterior span beam, thickened bottom slab).

Chart 12. Total post-tensioned strand requirement (exterior span beam, no Stage 2 post-tensioning).

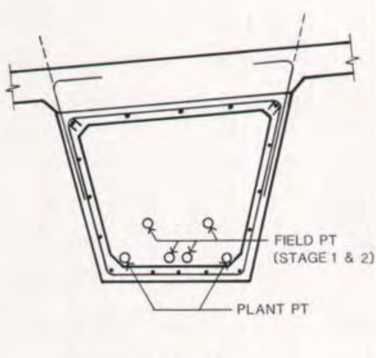



**PLAN**

* SPAN LENGTH IS AT ℄ BRIDGE. NOTE THAT DESIGN CHARTS ARE BASED ON MOMENTS IN THE OUTSIDE GIRDER.




**SECTION A–A**




**DETAIL ①**

NOTES :

- POST-TENSIONED (PT) TENDONS COMPROMISE 1/2"Ø-270K STRANDS.
- EFFECTIVE STRESS IN THE STRANDS AFTER CONSIDERING ALL LOSSES IS 160 KSI.
- STAGE 1 PT IS JACKED BEFORE THE CIP DECK IS PLACED.
- STAGE 2 PT IS JACKED AFTER THE CIP DECK IS PLACED.
- HS-20 LIVE LOAD.

Fig. B. Key plan, sections, and notes to be used with charts.

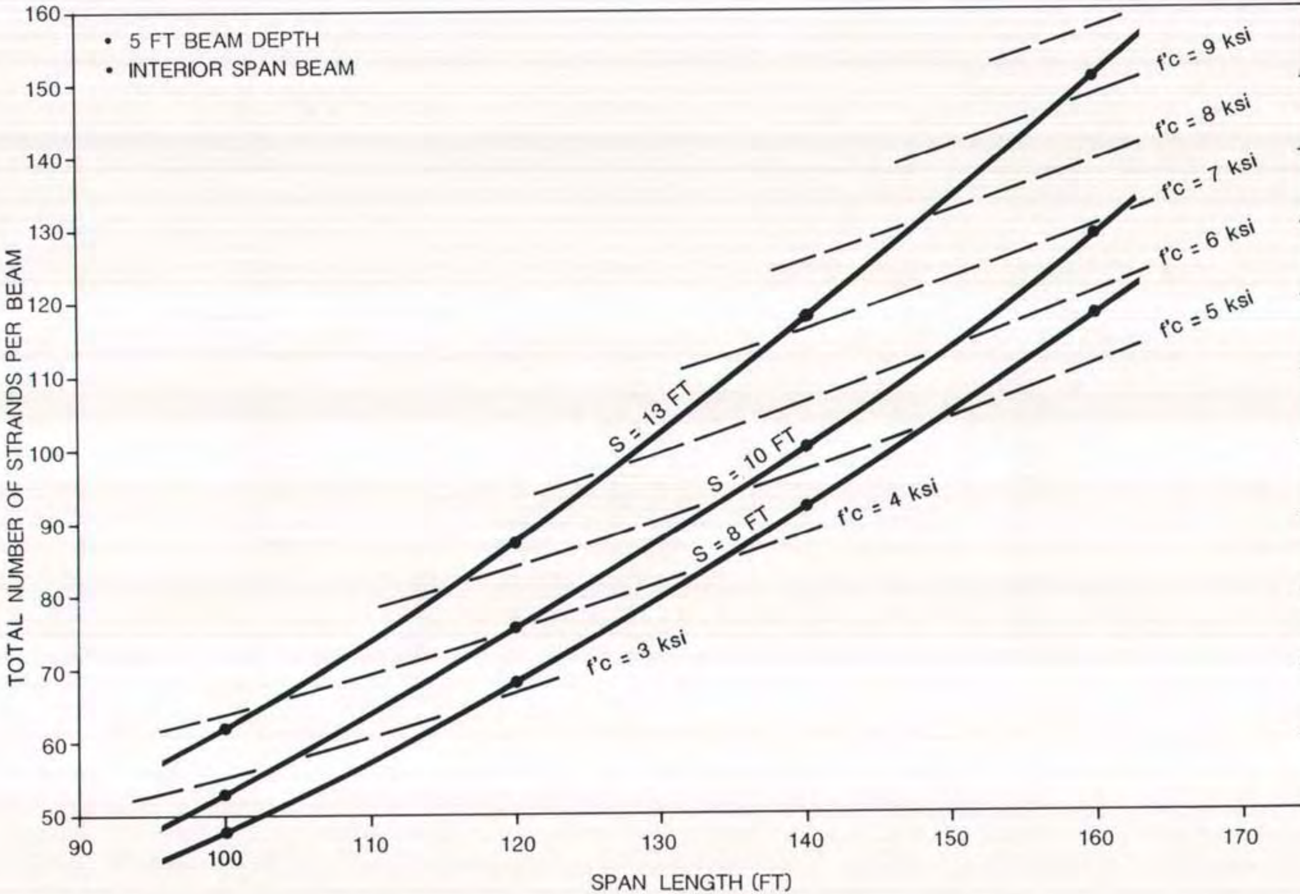



Fig. B1. Design chart.

**CHART 1 – TOTAL PT STRAND REQUIREMENT**

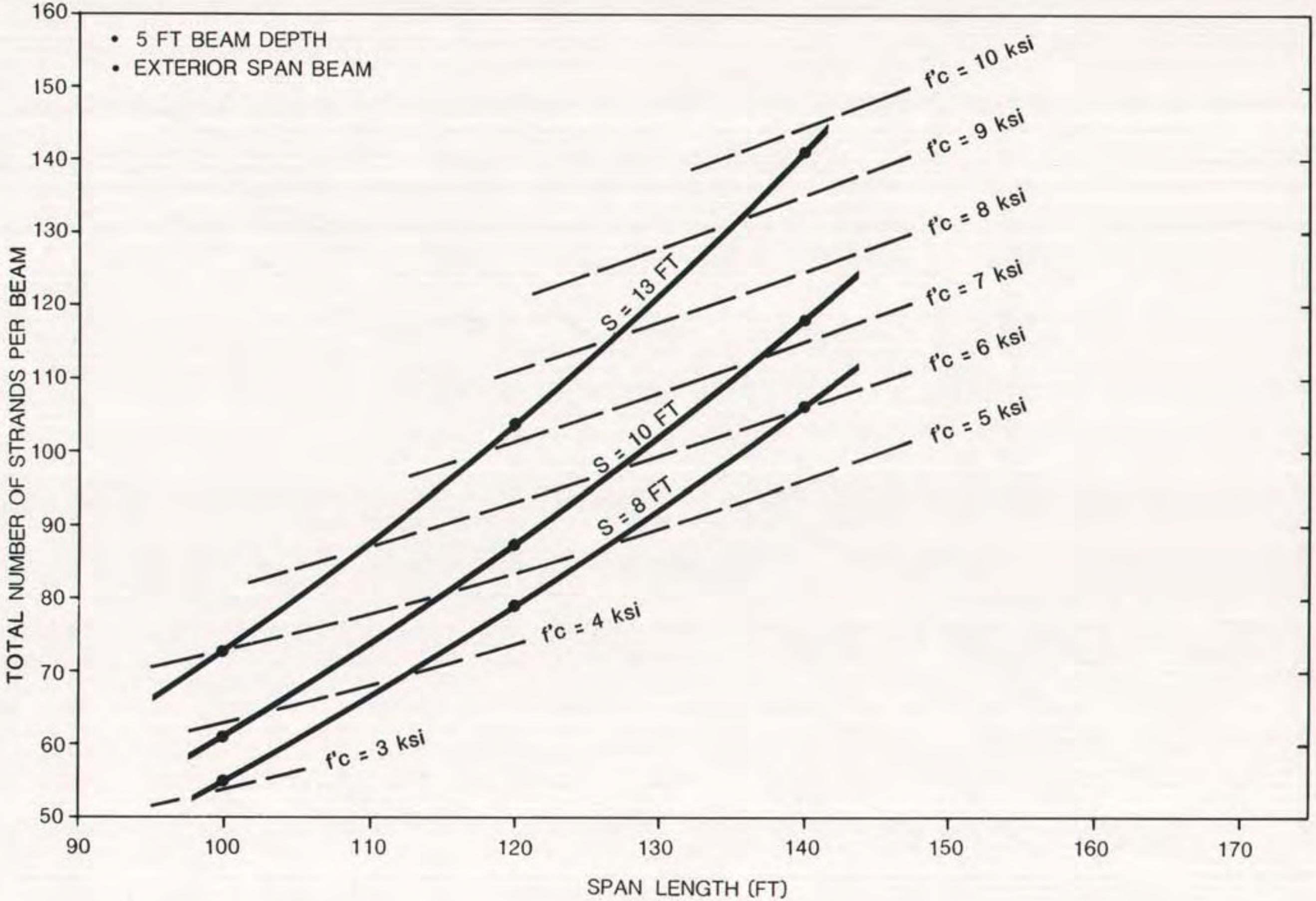



Fig. B2. Design chart.

**CHART 2 – TOTAL PT STRAND REQUIREMENT**

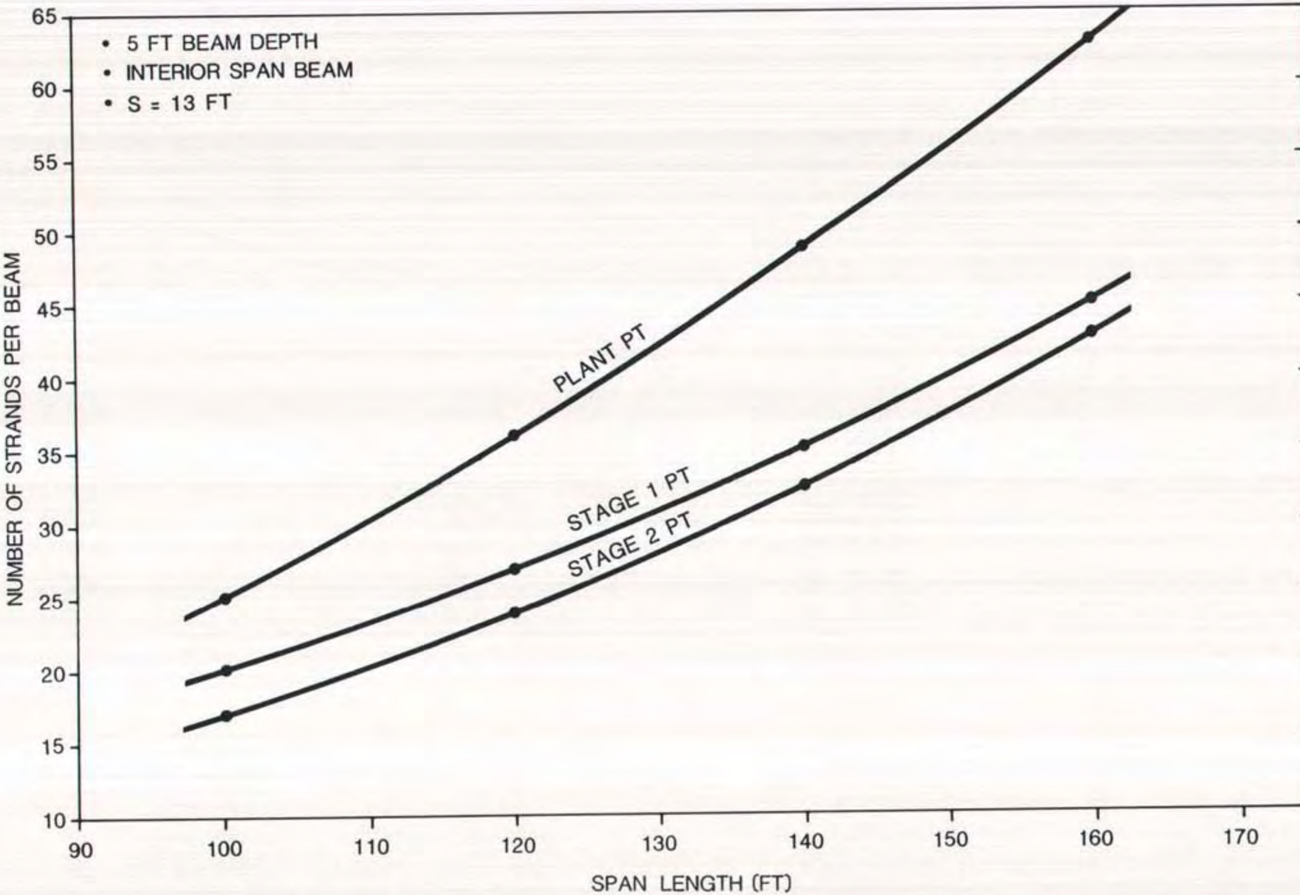



Fig. B3. Design chart.

**CHART 3 – PT STRAND REQUIREMENT**

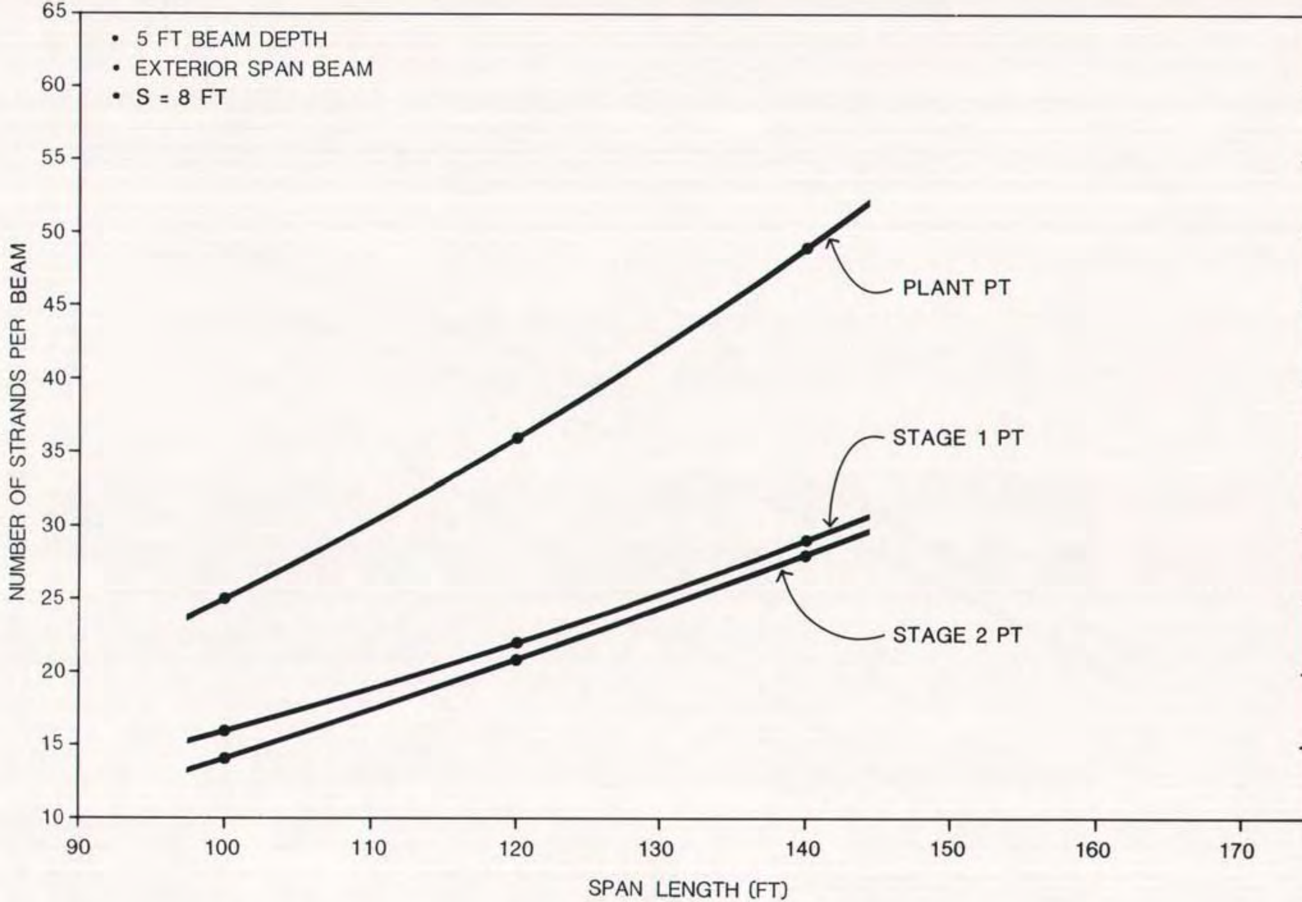



Fig. B4. Design chart.

**CHART 4 – PT STRAND REQUIREMENT**

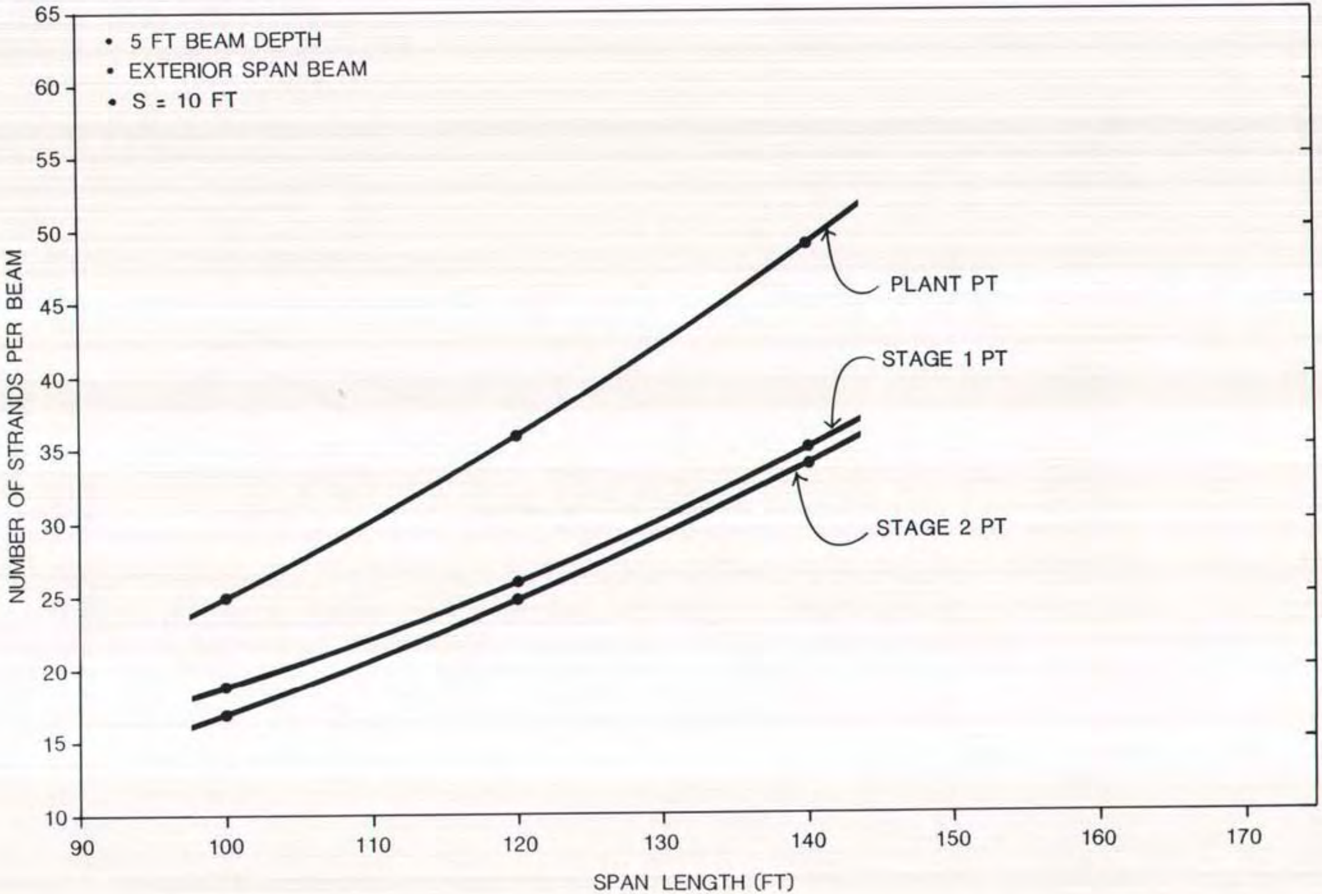



Fig. B5. Design chart.

CHART 5 – PT STRAND REQUIREMENT

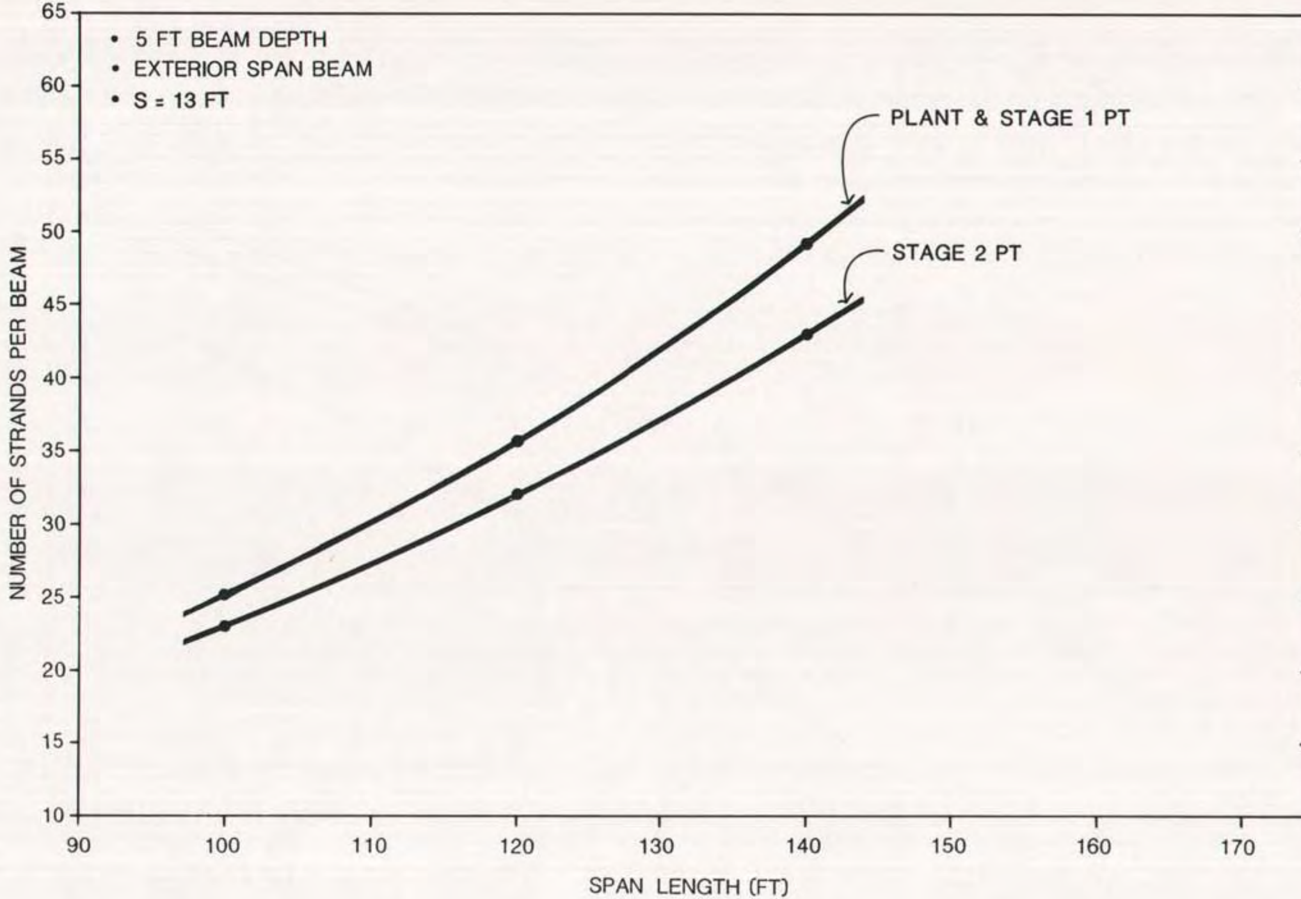



Fig. B6. Design chart.

**CHART 6 – PT STRAND REQUIREMENT**

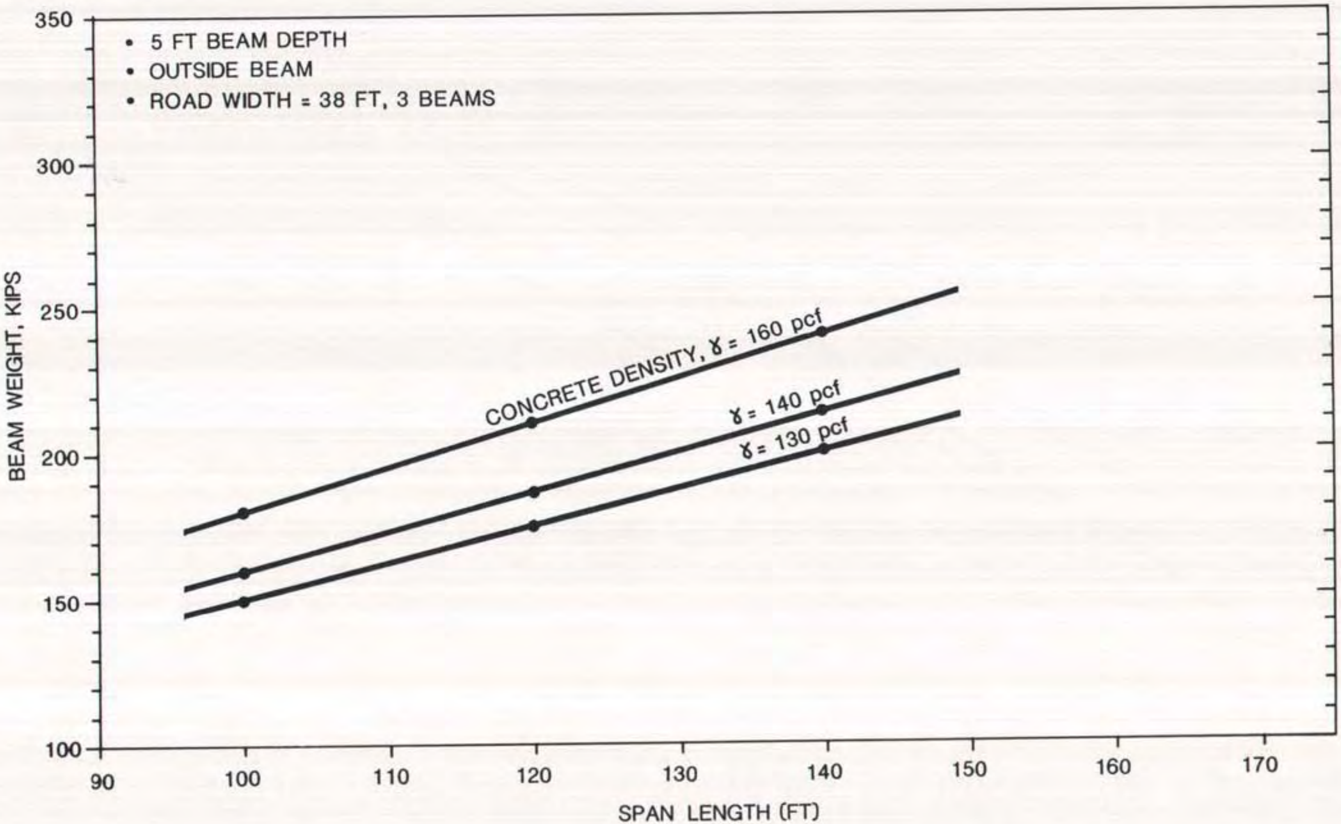



Fig. B7. Design chart.

**CHART 7 – BEAM SHIPPING WEIGHT**

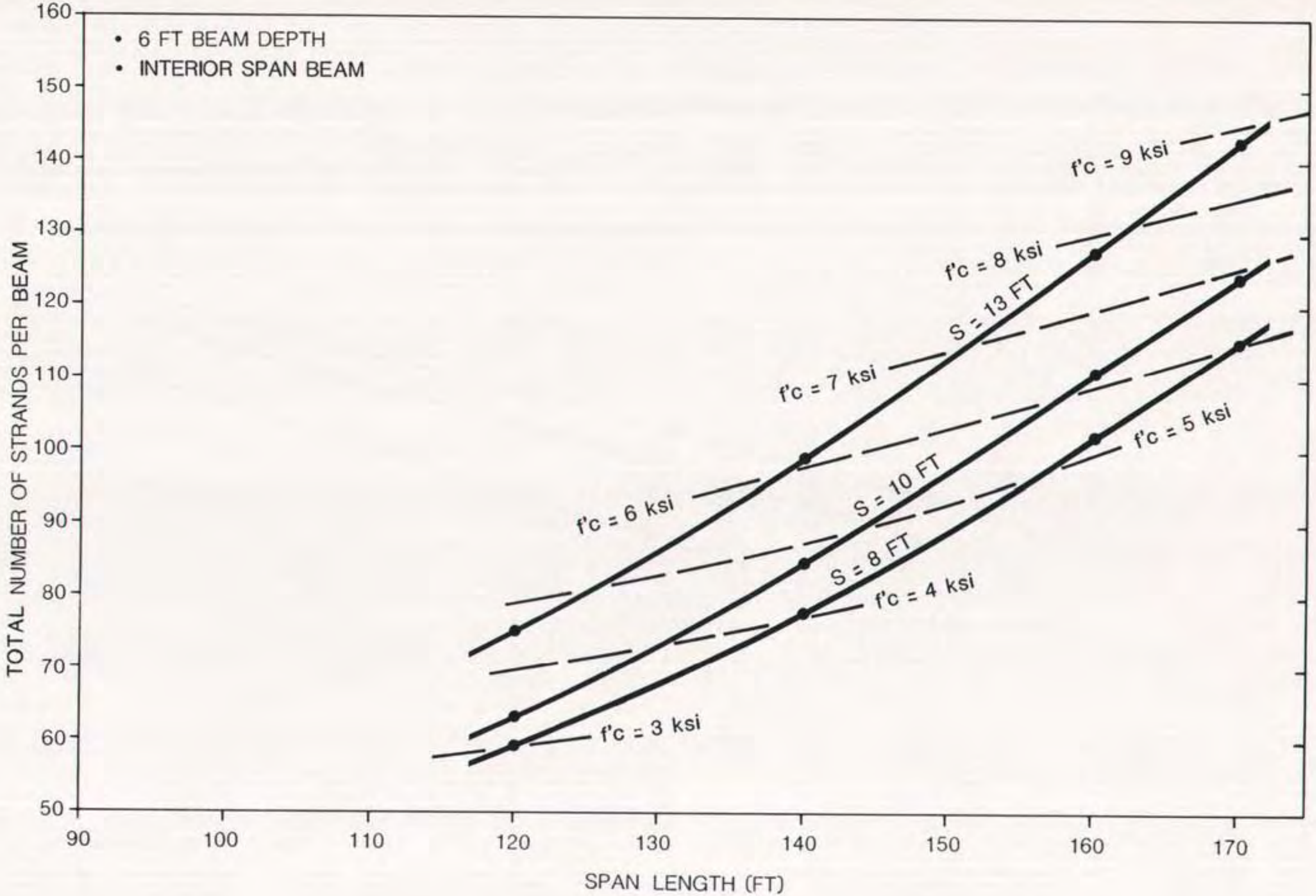



Fig. B8. Design chart.

**CHART 8 – TOTAL PT STRAND REQUIREMENT**

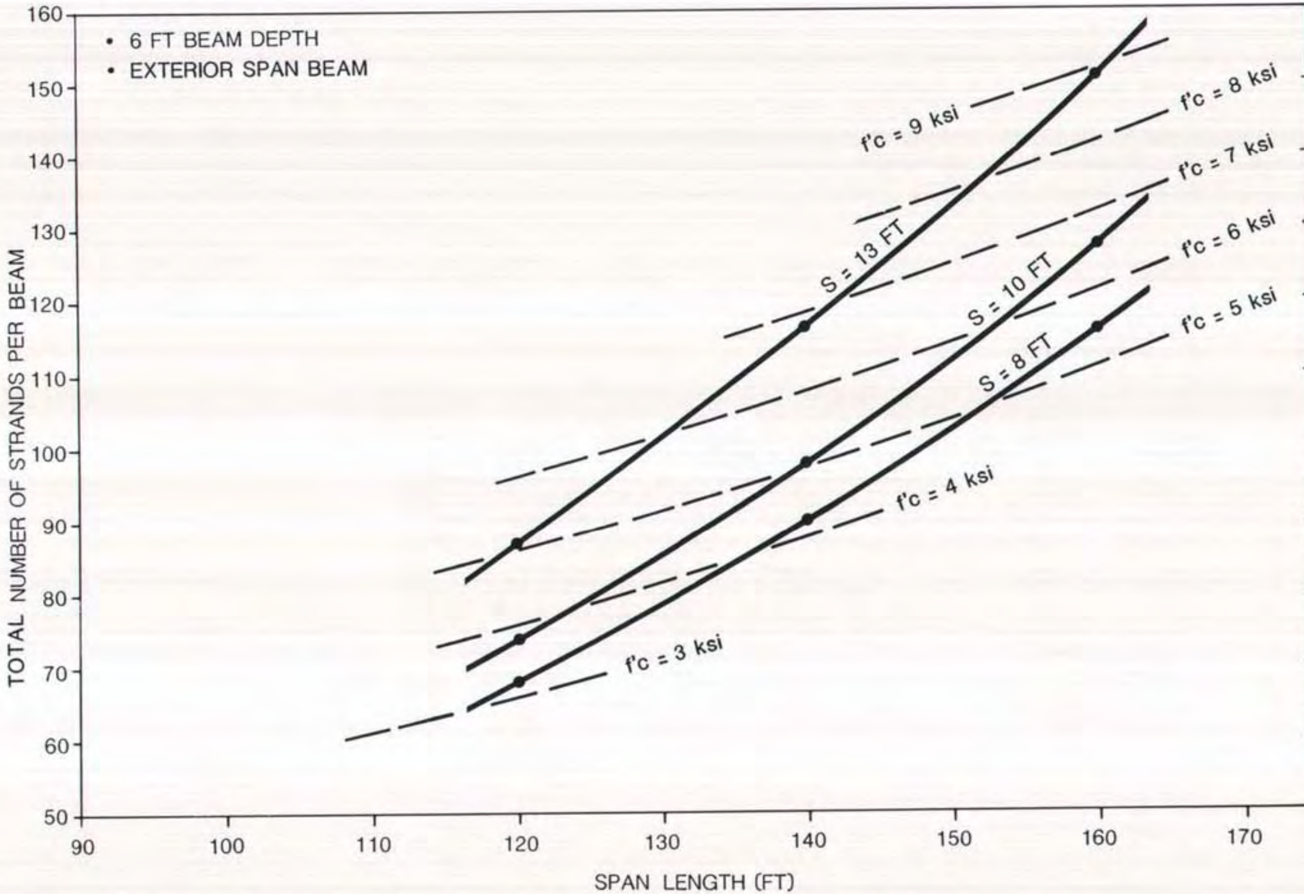



Fig. B9. Design chart.

**CHART 9 – TOTAL PT STRAND REQUIREMENT**

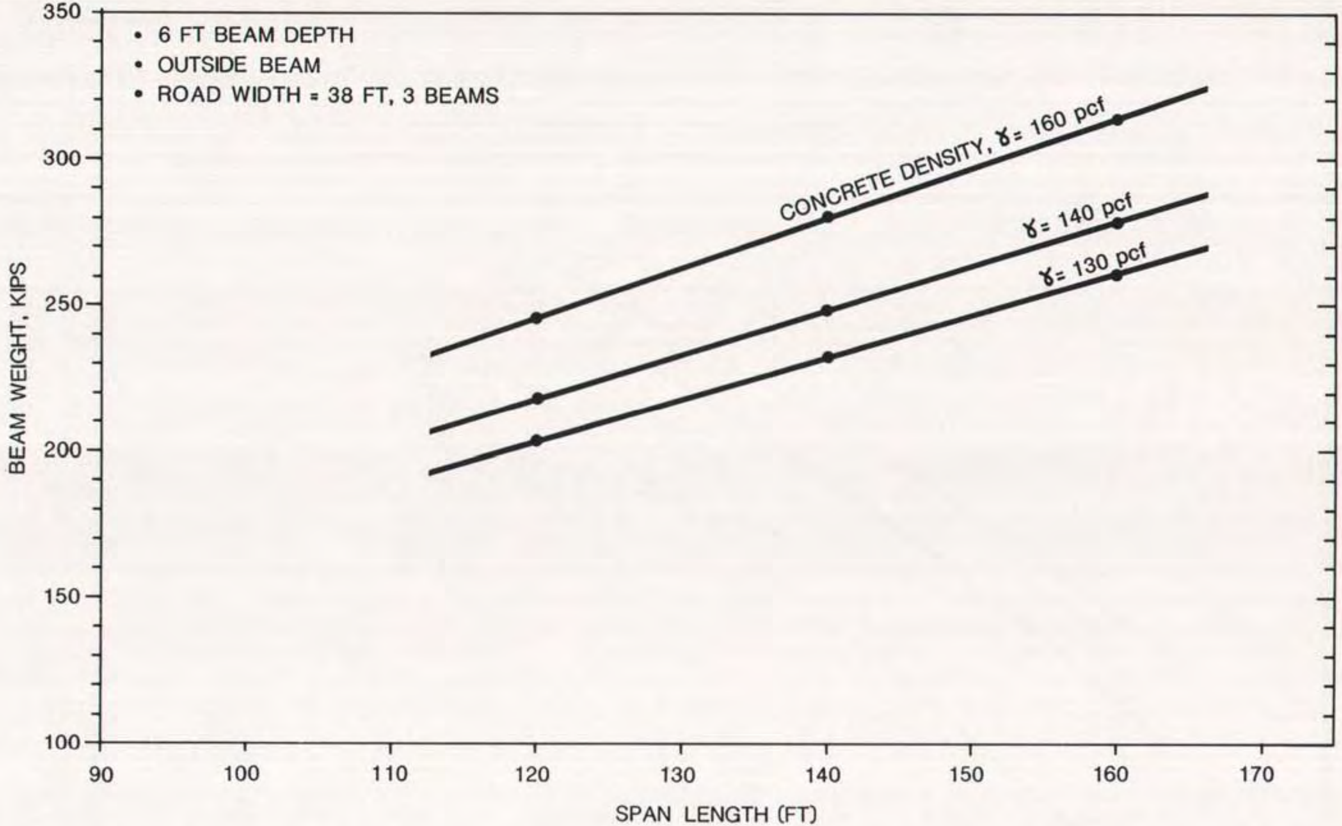



Fig. B10. Design chart.

**CHART 10 – BEAM SHIPPING WEIGHT**

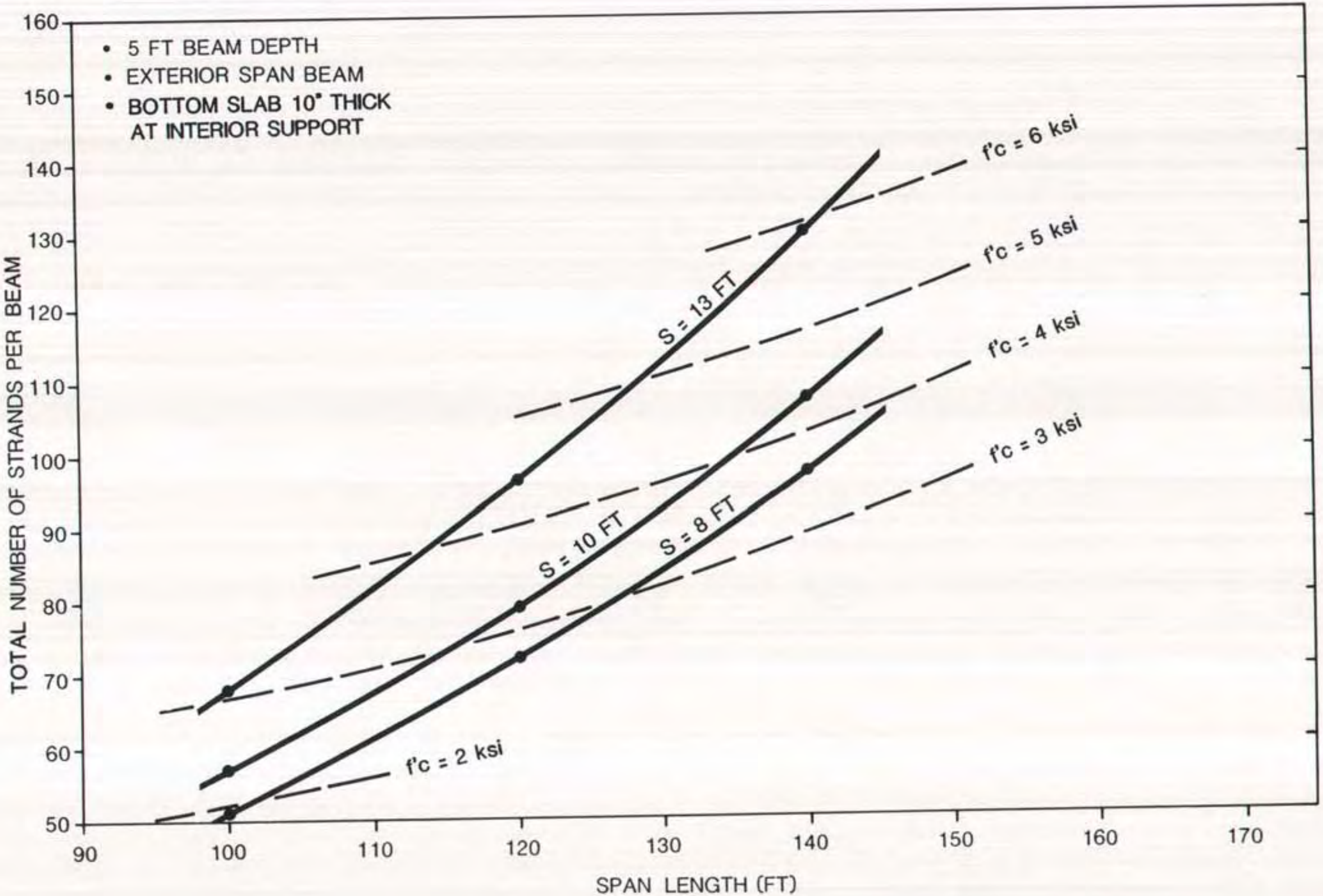



CHART 11 – TOTAL PT STRAND REQUIREMENT

Fig. B11. Design chart.

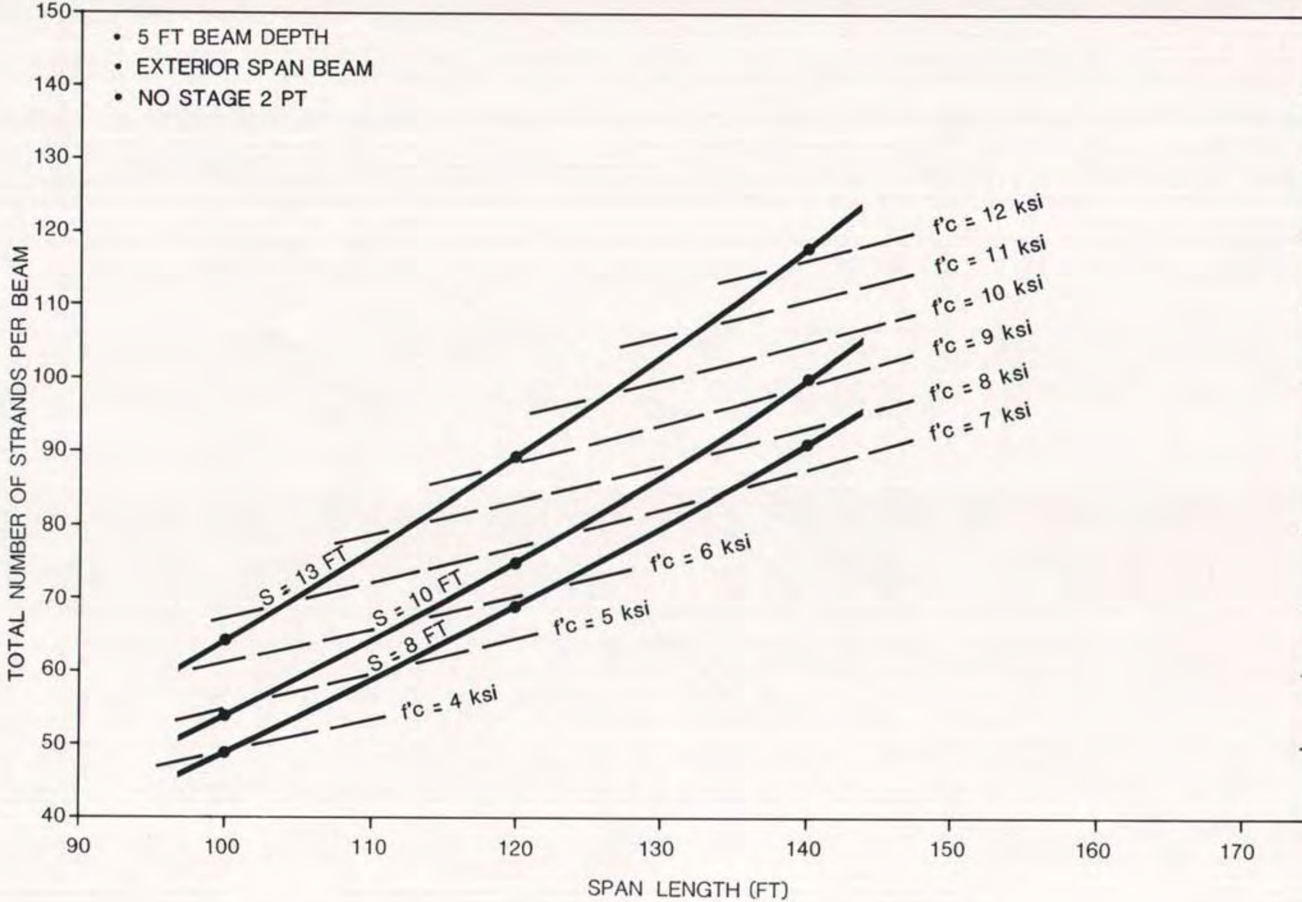
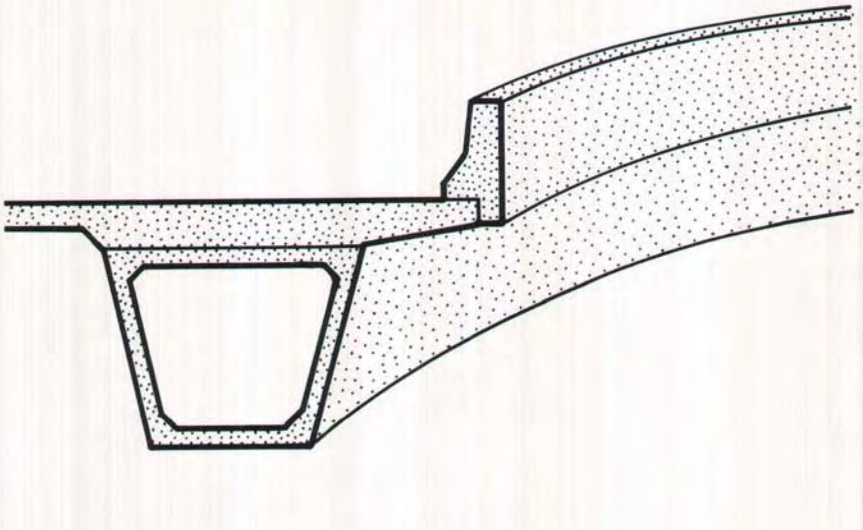



Fig. B12. Design chart.

**CHART 12 – TOTAL PT STRAND REQUIREMENT**

# APPENDIX C—DESIGN EXAMPLE



# APPENDIX C — DESIGN EXAMPLE

## Perform Preliminary Flexural Design

Bridge length = 380 ft (116 m)
Roadway width $W$ = 38 ft (11.6m)
Roadway radius $R$ = 300 ft (91.5 m)
Use beam depth = 5 ft (1.52 m)
Number of spans: 380/3 = 127 ft (38.7 m) avg
Try three spans.
380/4 = 95 ft (29.0 m) avg

The number of beams, $N_g$ (or beam spacing, $S$), can be determined from the design charts.

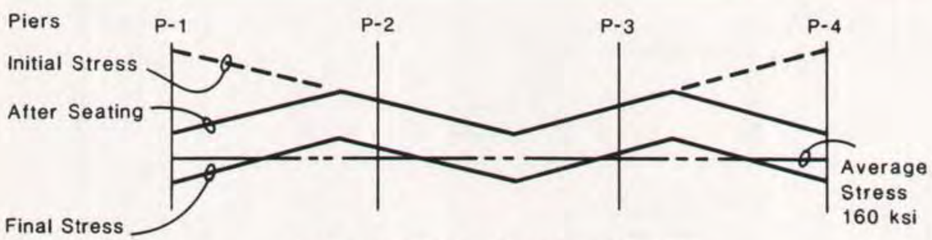
Try three beams [spacing = 13 ft (3.92 m)].

To optimize the post-tensioning design, enter 5 ft (1.52 m) beam depth charts (exterior and interior span beams) with plot of strand required versus span for three beams (see Figs. C1 and C2).

Find the combination of exterior and interior span lengths that add up to the total bridge length and that has the same number of strands required for each stage of field post-tensioning.

The plant post-tensioning supports the beam as a simple span and is not continuous; therefore, the required number of strands will be greater for the longer interior spans. It does not control the ratio of spans.

Stage 1 field post-tensioning is to support the cast-in-place bridge deck dead load and is continuous across interior supports. The number of strands is the same in the tendon. There will be some difference in the final stresses of the strand along the span from the end anchor to the center of the bridge (assuming stressing is done from both ends of the bridge) due to losses.




TENDON STRESS ALONG BEAM LINE

From the charts, find the spans that add up to the total length for the same number of strands in Stage 1:

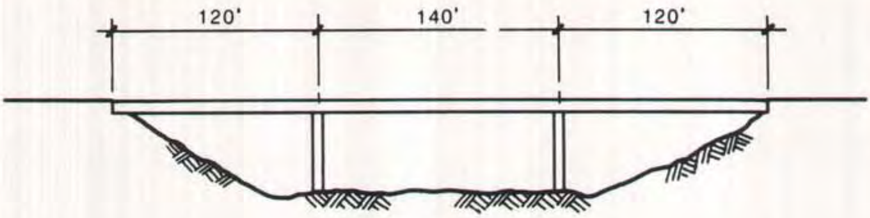
| | Span | Req'd. No. of strands |
|---|---|---|
| Exterior | 118.0 x 2 = 236 ft | 34.5 |
| Interior | 144.0 x 1 = 144 ft | 34.5 |
| | 380 ft | |

Using the same charts, similar calculations are done for determining the spans for Stage 2 post-tensioning:

| | Span | Req'd. No. of strands |
|---|---|---|
| Exterior | 122.5 x 2 = 245 ft | 33.0 |
| Interior | 135.0 x 1 = 135 ft | 33.0 |
| | 380 ft | |

The vertical lines plotted on the charts will bracket an efficient design solution. Any choice in between will require a few more strands.

By inspection, use:
Span = 120 + 140 + 120 = 380 ft (116 m)




BRIDGE ELEVATION

## Strand Required (Figs. C3 and C4):

| | By chart strand required | Adjusted strand requirement |
|---|---|---|
| Exterior span: 5 ft beam depth, three beams ($S$ = 13 ft) | | |
| Plant post-tension | 36 | 36 |
| Stage 1 post-tension | 36 | 36 |
| Stage 2 post-tension | 32 | 36* |
| | 104 | 108 |
| Interior span: 5 ft beam depth, three beams ($S$ = 13 ft) | | |
| Plant post-tension | 49 | 49 |
| Stage 1 post-tension | 33 | 36* |
| Stage 2 post-tension | 36 | 36 |
| | 118 | 121 |

*Increase

## Required 28-Day Compressive Strength (see Figs. C3 and C4)

Exterior span: $f'_c$ = 7300 psi (50.4 MPa)
Interior span: $f'_c$ = 7200 psi (49.7 MPa)
Say: $f'_c$ = 7500 psi (51.7 MPa)

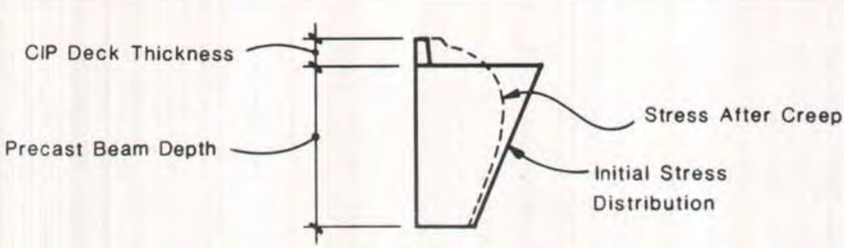
This requirement can be significantly reduced by thickening the bottom slab near the interior continuous supports, because the compressive strength requirements shown on the charts are generally governed by compression in the bottom slab at the interior support (see Fig. C5).

There are significant compressive stresses at the top of the bare beam at midspan prior to casting the deck; however, service level stresses in the deck are relatively low, allowing creep effects to reduce the compressive stress in the beam.

$f'_c$ might be reduced to 6000 psi (41.4 MPa).
Exterior span = 4500 psi (31.0 MPa)

## Beam Shipping Weight (see Fig. C6)

Exterior span beam shipping weight = 210 kips (934 kN)
Interior span beam shipping weight = 240 kips (1067 kN)




COMPRESSIVE STRESS AT MIDSPAN

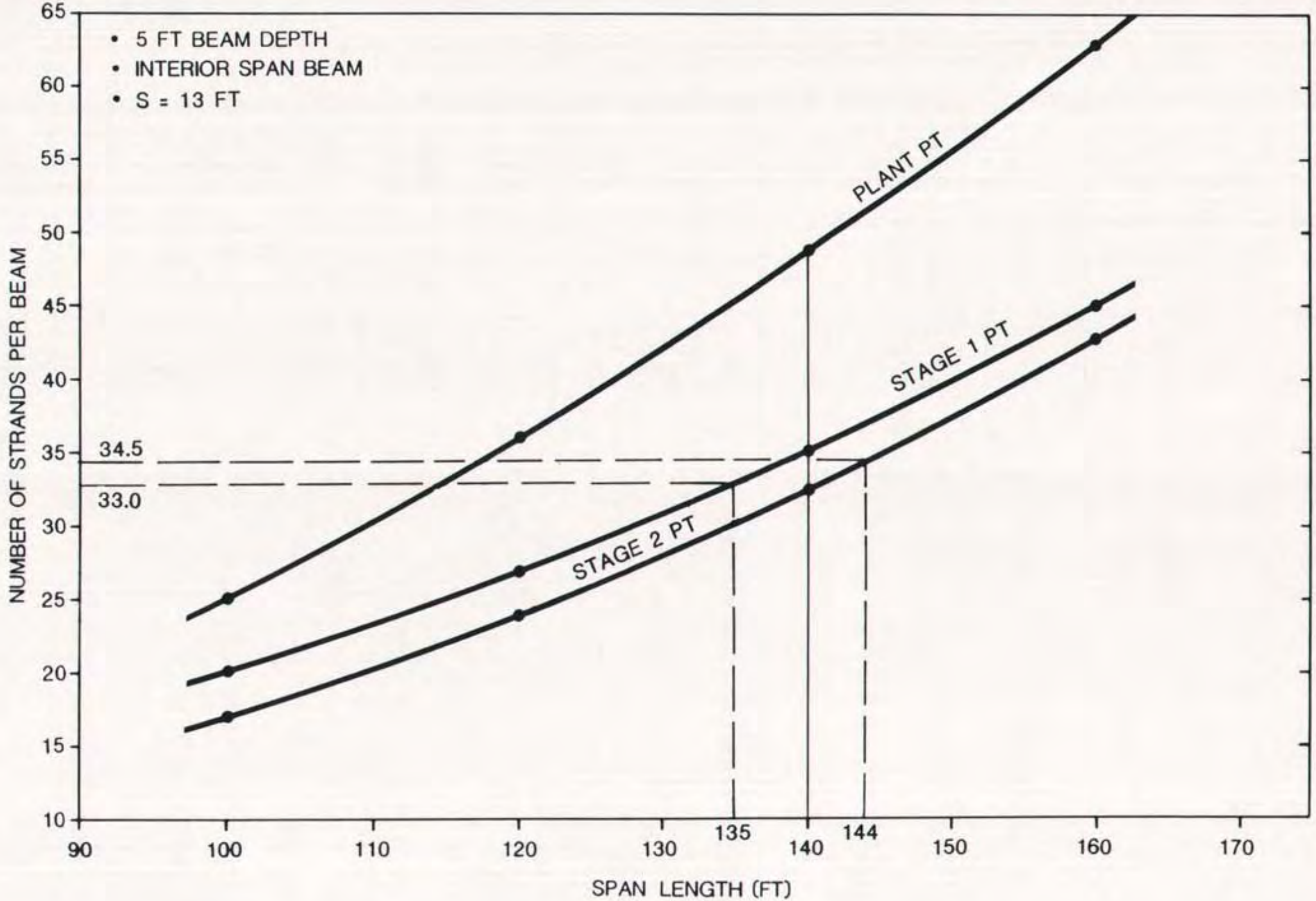



Fig. C1. Design Example.

**CHART 3 – PT STRAND REQUIREMENT**

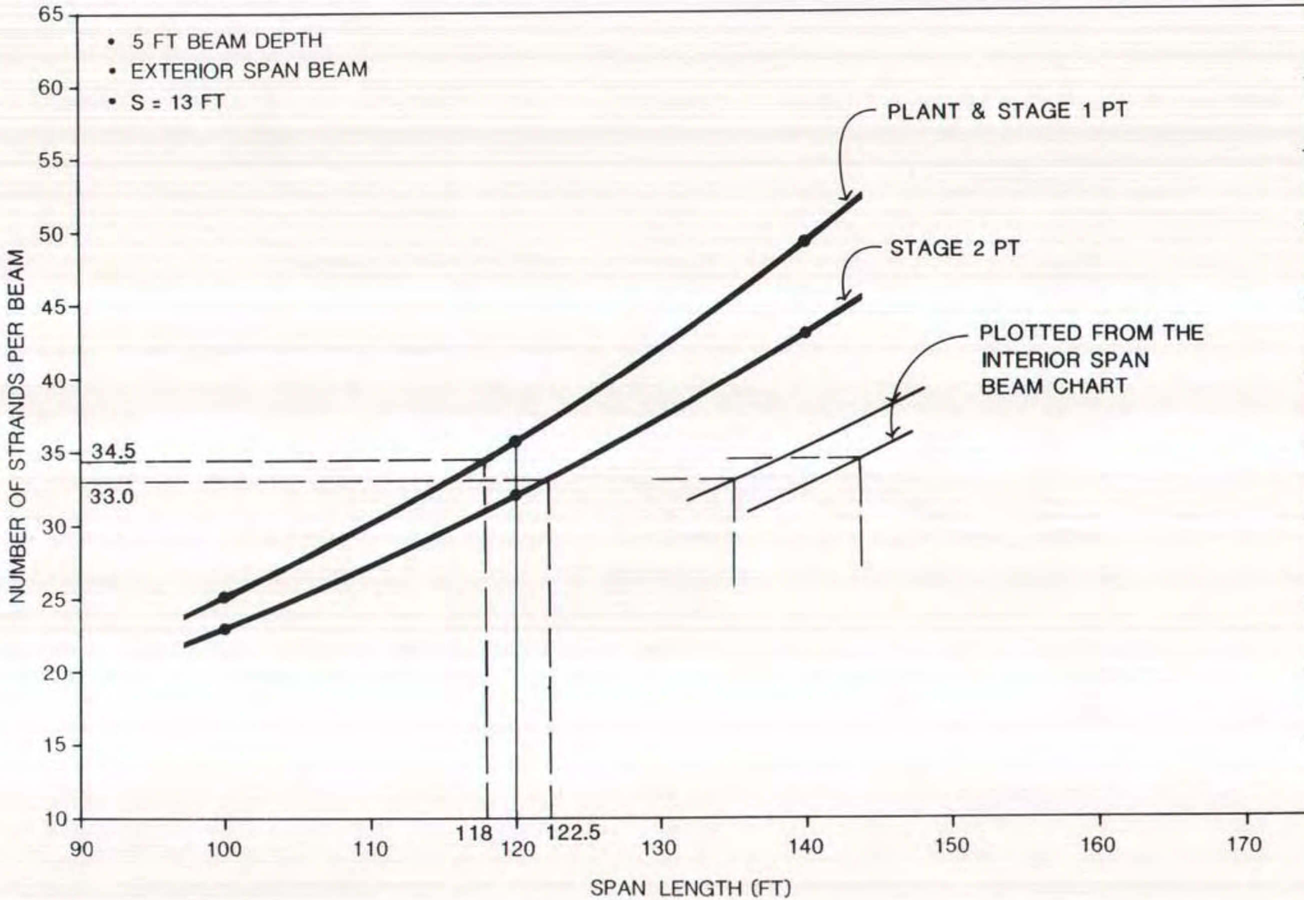



Fig. C2. Design Example.

**CHART 6 – PT STRAND REQUIREMENT**

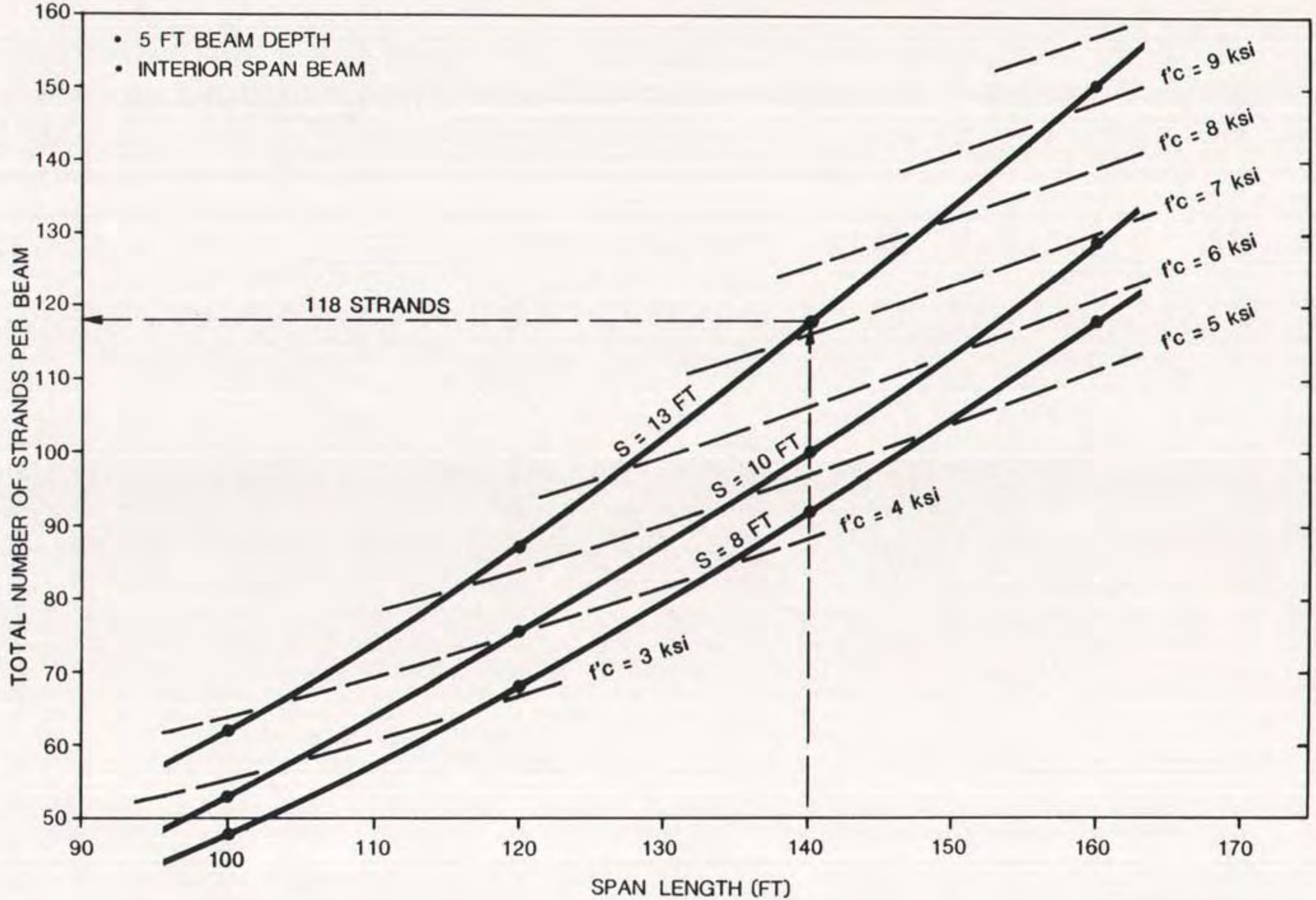



Fig. C3. Design Example.

**CHART 1 – TOTAL PT STRAND REQUIREMENT**

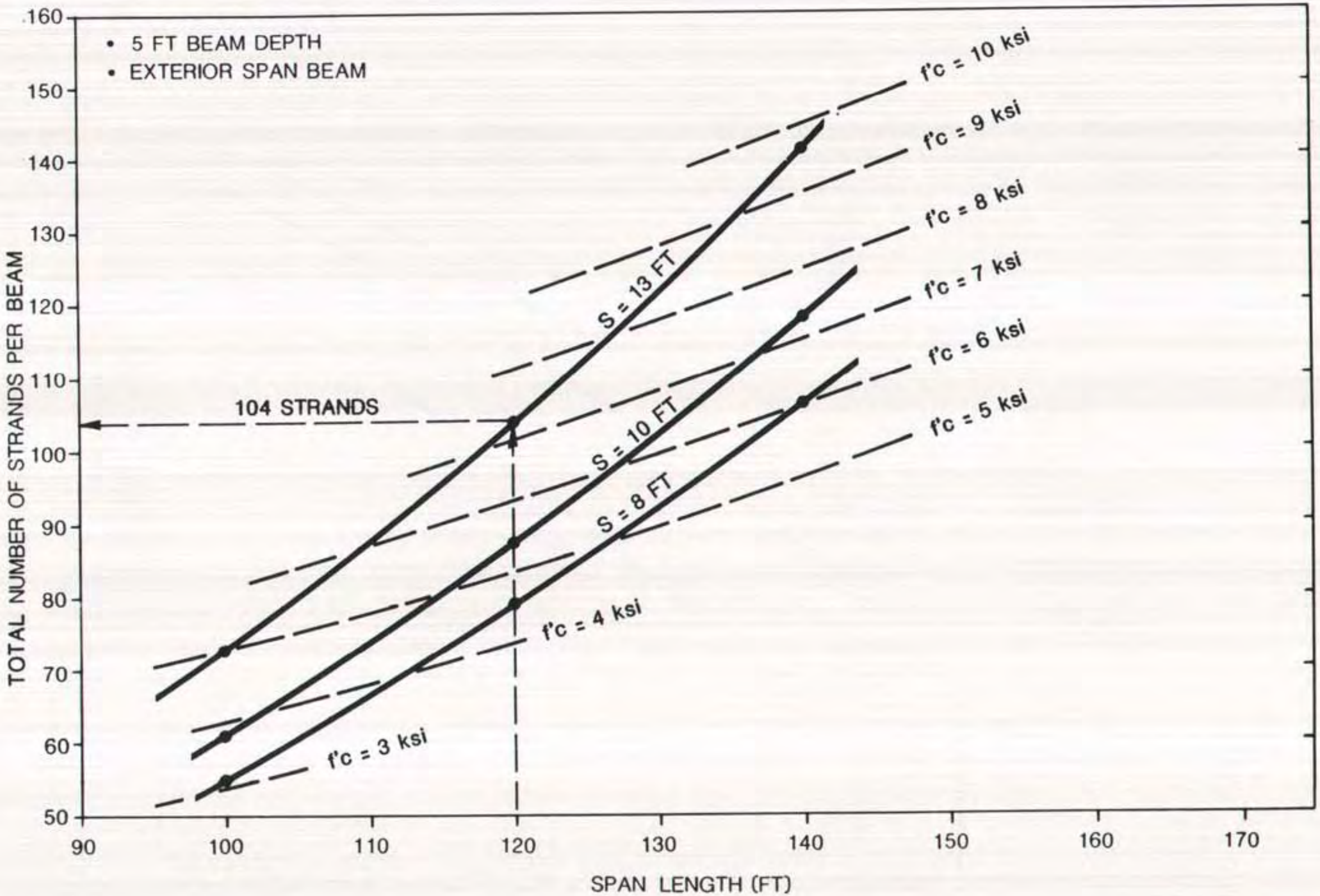



Fig. C4. Design Example

**CHART 2 - TOTAL PT STRAND REQUIREMENT**

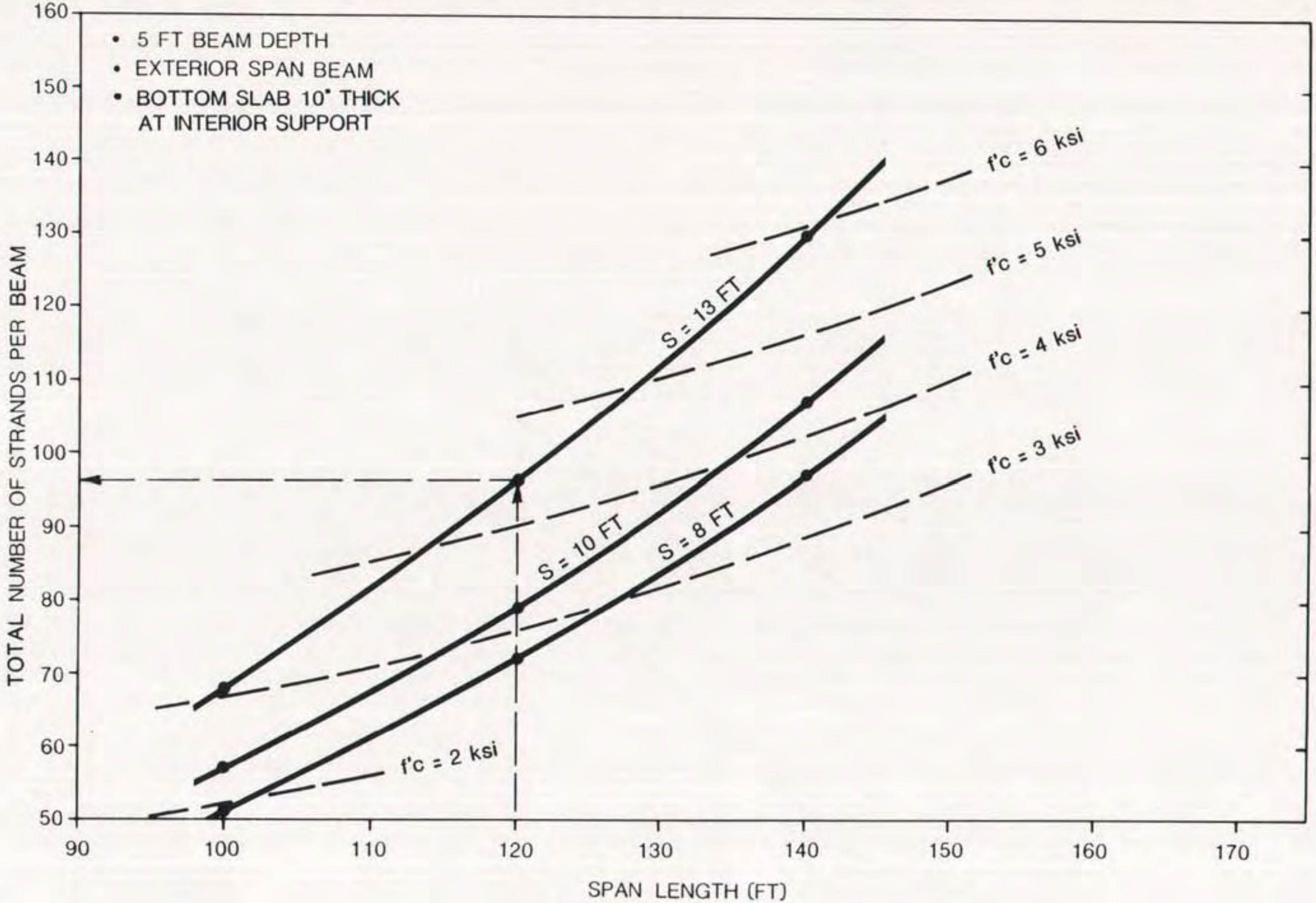



Fig. C5. Design Example.

**CHART 11 – TOTAL PT STRAND REQUIREMENT**

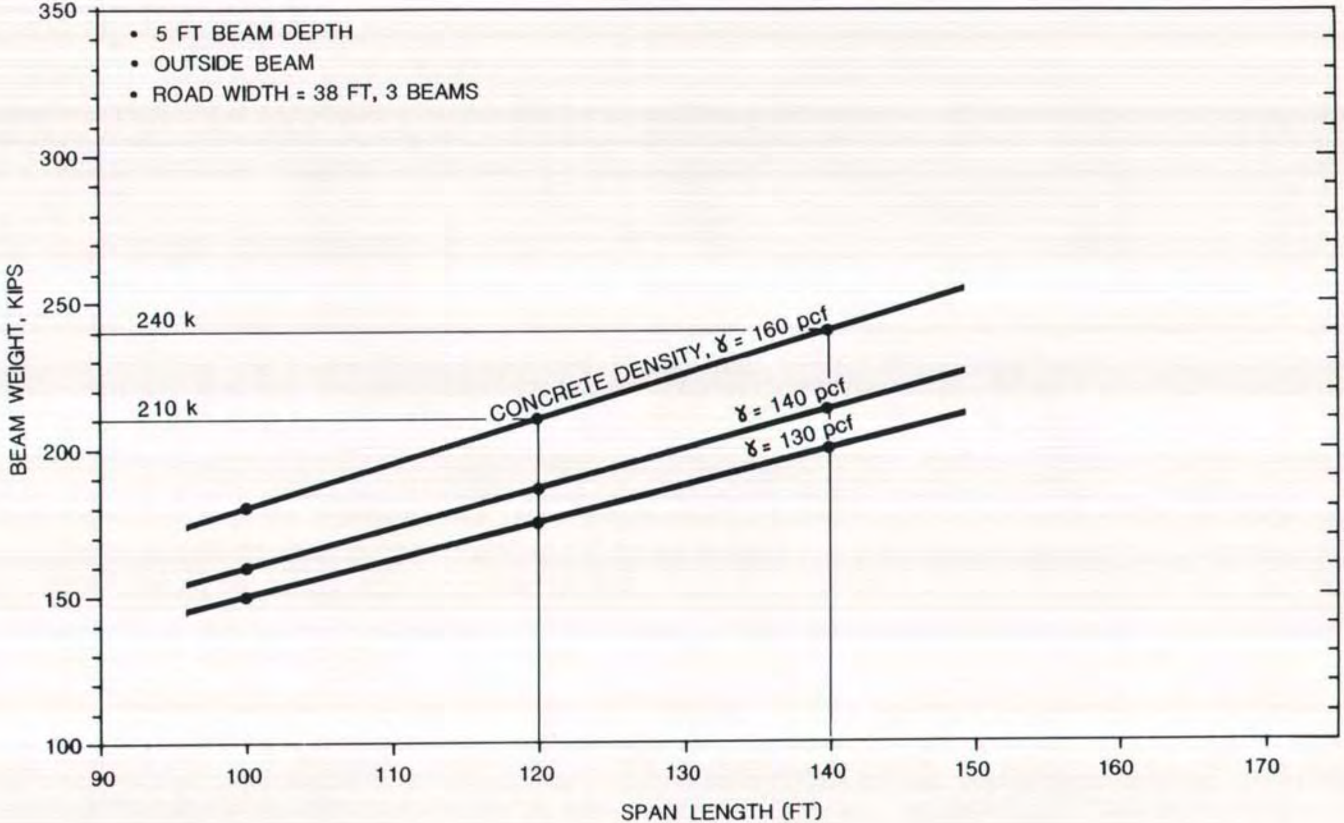



Fig. C6. Design Example.

**CHART 7 - BEAM SHIPPING WEIGHT**